PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

From the INTERNATIONAL BUREAU

To:

Commissioner
US Department of Commerce
United States Patent and Trademark
Office, PCT
2011 South Clark Place Room
CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 07 December 2000 (07.12.00)	
International application No. PCT/RU99/00272	**Applicant's or agent's file reference** PCT-148165
International filing date (day/month/year) 04 August 1999 (04.08.99)	**Priority date** (day/month/year) 03 September 1998 (03.09.98)
Applicant SEMENCHENKO, Mikhail Grigorievich	

1. The designated Office is hereby notified of its election made:

   [X] in the demand filed with the International Preliminary Examining Authority on:

   15 February 2000 (15.02.00)

   [ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was
   [ ] was not

   made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer F. Baechler Telephone No.: (41-22) 338.83.38

INTE[illegible]ATIONAL SEARCH REPORT

Im[illegible]ational Application No
PCT/RU 99/00272

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G06T5/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G06T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 756 247 A (FUJI PHOTO FILM CO LTD) 29 January 1997 (1997-01-29) abstract column 4, line 15 -column 5, line 17 column 5, line 30 - line 51 ---	1-23
A	US 5 708 693 A (AACH TIL ET AL) 13 January 1998 (1998-01-13) abstract column 2, line 21 - line 43 column 3, line 13 - line 65 ---	1-23
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 February 2000	25/02/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Gonzalez Ordonez, O

1

International Application No
PCT/RU 99/00272

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ANANDAKUMAR K ET AL: "NONLINEAR FILTERING USING GENERALIZED SUBBAND DECOMPOSITION" PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON IMAGE PROCESSING. (ICIP),US,LOS ALAMITOS, IEEE COMP. SOC. PRESS,1995, pages 382-385, XP000607766 ISBN: 0-7803-3122-2 paragraph '03.1! - paragraph '03.2! ---	1-23
A	US 5 526 446 A (ADELSON EDWARD H ET AL) 11 June 1996 (1996-06-11) column 7, line 1 - line 43 -----	1-23

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/RU 99/00272

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0756247 A	29-01-1997	JP 9044657 A	14-02-1997
		US 5960123 A	28-09-1999
US 5708693 A	13-01-1998	EP 0777891 A	11-06-1997
		WO 9701153 A	09-01-1997
		JP 10505443 T	26-05-1998
US 5526446 A	11-06-1996	JP 6245113 A	02-09-1994

NU

15

PATENT COOPERATION TREATY

REC'D 04 DEC 2000

WIPO PCT

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference PCT-148165	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/RU99/00272	International filing date *(day/month/year)* 04/08/1999	Priority date *(day/month/year)* 03/09/1998
International Patent Classification (IPC) or national classification and IPC G06T5/20		
Applicant SEMENCHENKO, Mikhail Grigorievich		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 6 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 26 sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the report
   II ☐ Priority
   III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   IV ☐ Lack of unity of invention
   V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   VI ☐ Certain documents cited
   VII ☐ Certain defects in the international application
   VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
15/02/2000	29.11.2000
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Knoepfle, R Telephone No. +49 89 2399 2659

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/RU99/00272

I. Basis of the report

1. This report has been drawn on the basis of *(substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments (Rules 70.16 and 70.17).)*:

Description, pages:

1-21	as received on	21/08/2000	with letter of	16/08/2000

Claims, No.:

1-23	as received on	21/08/2000	with letter of	16/08/2000

Drawings, sheets:

1/8-8/8	as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   - ☐ the description, pages:
   - ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1 - 23
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1 - 23
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1 - 23
	No:	Claims	

2. Citations and explanations
   see separate sheet

Re Item V

Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1). Reference is made to the following documents:

D1: EP-A-0 756 247;
D2: US-A-5 351 305.

2). The present application relates to a method of image preprocessing for enhancing sharpness and contrast of an image.

3). Document D2 cited by the Applicant in the present description is considered as the most relevant prior art document since - like in the present application - noise suppression is provided simultaneously with enhancement of contrast.

From document D2 an apparatus for smoothing and edge enhancing initial image representation is known. An image is processed in n frequency channels, each of the channels being represented by a matrix of the same size as the original image.

Thus an image processing method according to the precharacterising part of claim 1 is known from document D2.

5). It appears to be the problem of the present application
" to provide an improved method of image preprocessing for enhancing sharpness and contrast of an image combined with simultaneous noise suppression " (present description page 7, lines 3 and 4).

6). This problem is solved by the image processing method according to claim 1 of the present application by

- splitting the original image into a low frequency channel and n - 1 high frequency channels, and
- detection of edges by
- computation in each of n - 1 selected high frequency channels for each pixel of the

image,
- the correlation between processing pixel and its neighbouring pixels followed by
- comparison of said correlation value with correlation values for the corresponding (by their location in the image) pixels in other high frequency channels and with the threshold value for this channel,
- based on the results of said comparison, forming the weighting coefficients for each pixel of each of the n - 1 high frequency channels, and
- the assembly of the output image is made by summing each pixel value from the low frequency channel with all the corresponding (by their location in the image) pixel values of the n - 1 high frequency channels multiplied by their weighting coefficients.

7). In document D2 an edge detecting means views the region around each sampled pixel of the filtered image to determine an amount in the pixel values. A large deviation indicates an edge; whereas, substantial homogeneity indicates the lack of an edge. A plurality of soft edge directional filters operate on the filtered image data to create a plurality of soft edge directionally filtered image representations; and a plurality of hard edge directional filters operate on the filtered image data to create a plurality of hard edge directionally filtered image representations. Pixels which are adjacent an edge with a smaller (larger) rate of deviation are replaced by the corresponding pixel of the soft (hard) edge filtered image representation that was directionally filtered along a direction most nearly parallel to the determined edge detection.

8). The present image processing method claimed in claim 1 appears to be new and inventive in view of document D2 since in claim 1 quite another method as in document D2 is claimed.

9). From document D1 an image processing method and apparatus is known that enables an image portion with comparatively low level of contrast with surrounding image regions to become more perceptible.

The known method transforms an original image into a multiresolution space decomposing it into images, each of which is one of a plurality of different frequency bands. Emphasis processing is carried out on an image of a preset frequency band by setting the degree of emphasis such that the degree of emphasis for a picture element of the image with an intensity value larger than a preset threshold value is set lower

than the degree of emphasis for other picture elements of the image of that band (cf. abstract of document D1).

10). Since D1 provides only enhancing contrast of an image by splitting the image into isotropic frequency channels and carrying out enhancing processing in each channel on images of different sizes (column 12, lines 19 to 26 in conjunction with Figure 6) and does not provide noise suppression, the subject-matter of claim 1 which provides contrast enhancement and noise suppression simultaneously is considered new and nonobvious.

11). Therefore independent claim 1 meets the requirements of Articles 33(2) and (3) PCT.

12). Dependent claims 2 to 23 specify advantageous embodiments of the method of claim 1 and therefore also meet the requirements of Articles 33(2) and (3) PCT.

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference PCT-148165	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/RU 99/ 00272	International filing date *(day/month/year)* 04/08/1999	(Earliest) Priority Date *(day/month/year)* 03/09/1998
Applicant SEMENCHENKO, Mikhail Grigorievich		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

   [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

   [ ] contained in the international application in written form.
   [ ] filed together with the international application in computer readable form.
   [ ] furnished subsequently to this Authority in written form.
   [ ] furnished subsequently to this Authority in computer readble form.
   [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).
3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title**,

   [X] the text is approved as submitted by the applicant.
   [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

   [X] the text is approved as submitted by the applicant.
   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 1

   [X] as suggested by the applicant. [ ] None of the figures.
   [ ] because the applicant failed to suggest a figure.
   [ ] because this figure better characterizes the invention.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/RU 99/00272

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G06T5/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G06T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 756 247 A (FUJI PHOTO FILM CO LTD) 29 January 1997 (1997-01-29) abstract column 4, line 15 -column 5, line 17 column 5, line 30 - line 51 ---	1-23
A	US 5 708 693 A (AACH TIL ET AL) 13 January 1998 (1998-01-13) abstract column 2, line 21 - line 43 column 3, line 13 - line 65 ---	1-23
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 February 2000	25/02/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Gonzalez Ordonez, O

1

International Application No
PCT/RU 99/00272

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	ANANDAKUMAR K ET AL: "NONLINEAR FILTERING USING GENERALIZED SUBBAND DECOMPOSITION" PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON IMAGE PROCESSING. (ICIP),US,LOS ALAMITOS, IEEE COMP. SOC. PRESS,1995, pages 382-385, XP000607766 ISBN: 0-7803-3122-2 paragraph ‘03.1! - paragraph ‘03.2! ---	1-23
A	US 5 526 446 A (ADELSON EDWARD H ET AL) 11 June 1996 (1996-06-11) column 7, line 1 - line 43 -----	1-23

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/RU 99/00272

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0756247 A	29-01-1997	JP 9044657 A	14-02-1997
		US 5960123 A	28-09-1999
US 5708693 A	13-01-1998	EP 0777891 A	11-06-1997
		WO 9701153 A	09-01-1997
		JP 10505443 T	26-05-1998
US 5526446 A	11-06-1996	JP 6245113 A	02-09-1994

PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : G06T 5/20	A1	(11) International Publication Number: **WO 00/14684** (43) International Publication Date: 16 March 2000 (16.03.00)

(21) International Application Number: PCT/RU99/00272

(22) International Filing Date: 4 August 1999 (04.08.99)

(30) Priority Data:
98116546 3 September 1998 (03.09.98) RU

(71)(72) Applicant and Inventor: SEMENCHENKO, Mikhail Grigorievich [RU/RU]; ul. Orbeli, 25-5-35, St.Petersburg, 194223 (RU).

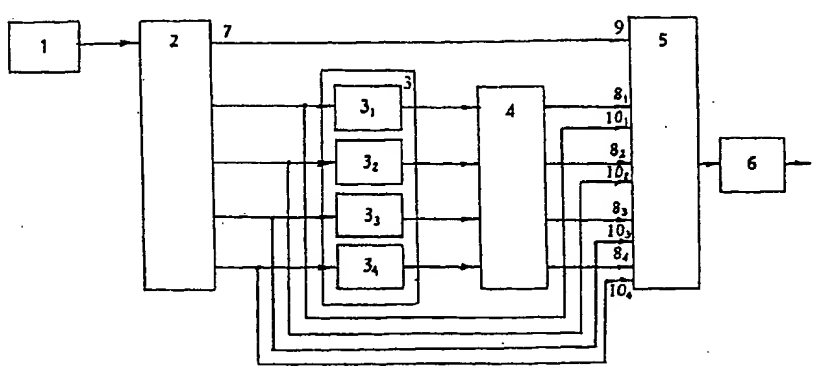
(74) Agent: KORCHEMNAYA, Ljubov Mikhailovna; Advokatskaya patentnaya kontora "Rotary", a/ya 44, St.Petersburg, 198260 (RU).

(81) Designated States: AL, AT, AU, BA, BB, BG, BR, CA, CN, CU, CZ, DE, DK, EE, FI, GB, GE, HU, ID, IL, IS, JP, KP, KR, LK, LR, LT, LV, MG, MK, MN, MX, NO, NZ, PL, RO, SE, SG, SI, SK, TR, TT, UA, US, UZ, VN, YU, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published

With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: IMAGE PROCESSING METHOD



(57) Abstract

The present invention relates to the automatics and computation techniques and, more particularly, to methods of the preliminary image processing for sharpening and contrast enhancement. The object of the present invention is to provide a method for enhancing of the image sharpness and contrast in conjunction with simultaneous noise suppression. To achieve this objective, in the image processing method, comprising the presentation of the original image as a matrix of the discreet picture elements, splitting of the original image into n frequency channels, each channel presented by an image matrix of the same size as the original image, the edge detection, and assembling of the output (enhanced) image from the indicated n frequency channels, said assembling takes the detected edges into account, characterized by selection of the low frequency channel and n−1 high frequency channels while splitting the original image into frequency channels, and edge detection by computation in each of n−1 selected high channels of the correlation between processing pixel and its neighboring pixels followed by the comparison of the correlation value with that for the corresponding pixels in other high frequency channels and with the threshold value for this channel. Basing on the results of comparaison, the weighting coefficients are formed for each pixel of each of n−1 high frequency channels, and the assembly of the output image is made by summing of each pixel from the low frequency channel with all products of the corresponding (by their location in the image) pixels of n−1 high frequency channels by their weighting coefficients.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

IMAGE PROCESSING METHOD

TECHNICAL FIELD

The present invention relates to the automatics and computation techniques and, more particularly, to methods of the preliminary image processing for sharpening and contrast enhancement.

BACKGROUND ART

One of the methods known in the prior art is described in the Russian Patent No.2015561, published on 16.04.91, Int. Class G06K 9/40. According to this invention, the image correction is made basing on the analysis of the original image at the processing pixel and the local average value over some neighborhood of this pixel.

The method of that patent smoothes the original image, thus producing the smoothed image containing the low frequency components presenting the image background. Then the smoothed image is subtracted from the original one producing the second image containing high frequency components without background, said second image is then emphasized and added to the smoothed image.

The disadvantage of this method is that it emphasizes not only the useful signal but also the noise containing in high frequency image components, thus

degrading the quality of the enhanced image.

The method according to U.S. Patent No. 5,038,388, published on 06.08.91, Int. Class G06K 9/40 smoothes the original image and subtracts the smoothed image from the original one thus producing the second image containing the high frequency image components only. Said second image is then adaptively emphasized so that the scaling factor is then higher than larger is a difference between the processing pixels and its neighborhood. The output image is produced by adding the adaptively emphasized second image to the original image, thus sharpening the image without the noise amplification.

The solution described in this patent does not provide any noise suppression as this method can only emphasize the high frequency image components that may contain a noise.

Furthermore, the disadvantage of this method known in the art is that it fails to improve considerably the sharpness of weak edges as such enhancement requires to emphasize the high frequency image components in the regions where a difference between the processing pixel and its neighborhood is comparable to the noise level. Therefore the edge enhancement in such regions causes the noise emphasis.

According to the image processing method disclosed in U.S. Patent No. 5,381,490, published on 10.01.95, Int. Class G06K 9/40 the largest difference Δ between the processing pixel and its nearest neighbors is calculated. Depending on the magnitude of this difference, one of the three processing modes is selected:

- the edge enhancement by means of emphasis of the high frequency image components if $\Delta > T_1$, here T_1 presents the first pre-defined threshold value;

- reproduction of the original image, if $T_2 < \Delta < T_1$, where T_2 stands for the second pre-defined threshold value.

- the image smoothing to suppress a noise, if $\Delta < T_2$.

The first disadvantage of this method is that it may emphasize the noise selectively if the difference Δ varies around any of the threshold values for some neighboring pixels thus transforming small differences between neighboring pixels into larger ones by involving different processing modes for these neighboring pixels.

Furthermore, this method fails to provide quality enhancement of images with different noise magnitudes without tuning as the threshold values T_1 and T_2 are not selected adaptively.

Another approach to the noise suppression in images is described in U.S. Patent 5,563,963, published on 08.10.96, Int. Class G06K 9/40. The method of this patent operates by selecting a plurality of groups of neighbors for each pixel of the original image, each group being a square containing N x N pixels, here N varies for example from 2 to 21. The processing pixel may be located at any position inside this square group of pixels. The least square best fit plane (the planar approximation) is used then to approximate pixel values in each of selected pixel groups and the new value for the processing pixel and the goodness of fit are computed basing on said approximation for each group.

The target pixel of an enhanced image is produced by the weighted summing of all the new pixel values, the weight of a group is then higher than higher is the goodness of fit for this group.

The disadvantage of this method is that it fails to enhance edges as this method provides the noise smoothing only. Furthermore, this method requires huge

computation efforts to build least square approximations by hundreds of groups for each of hundreds of thousands of pixels.

The method disclosed in U.S. Patent 5,739,922, published on 14.04.98, Int. Classes G06K 9/40, H04N 1/40 operates by splitting of the original color image into three isotropic frequency channels: the low frequency image components (LF), the medium frequency components (MF) and the high frequency components (HF). The adaptive emphasis of the HF components and adaptive suppression of the MF components is then carried out, thereat the multipliers for HF and MF image components are then higher than higher is a correlation between at least two of three basic image colors. The enhanced image is obtained by summing LF image components with adaptively suppressed MF components and adaptively emphasized HF image components.

The image processing method and apparatus described in said patent may have the limited application as they are suitable for color images only as the correlation between color components is used for carrying out the image processing.

Furthermore, the noise suppression according to this invention is significantly limited, as the HF image components, that also contain a noise, may be emphasized only and the noise suppression in MF image components is limited because no directional splitting of the original image is used.

The edge detection and enhancement can not be obtained by this method as the isotropic frequency channels are used.

All these disadvantages degrade the quality of enhanced images.

The most relevant image processing method is described in U.S. Patent No. 5,351,305, published on 27.09.94, Int. Class G06K 9/40. According to this patent,

a plurality of directionally filtered images is obtained from the original image by applying directional filters in the frequency domain. The enhanced image is then formed by selecting each target pixel either from the directionally filtered image, if the contrast edge is detected nearby the processing pixel or from the original image otherwise. Thereat the contrast edge is detected nearby the processing pixel by generating the standard deviation image and by producing the eigenvector description of this image. The eigenvector length is compared to the predetermined threshold value to detect an edge.

The target pixel is equal to the corresponding pixel of the original image, if the edge was not detected nearby. Otherwise, the target pixel is selected from an image filtered with the most nearly corresponding direction of filtering.

While detecting edges, the eigenvector length may vary around the threshold value for several adjacent pixels. Thereby the neighboring pixels of the enhanced image are selected from different images (the original image and directionally filtered image) thus causing the selective noise emphasis. This emphasis degrades the enhanced image quality.

Furthermore, original images may differ in their noise levels thus requiring different threshold values. This method does not include the adaptive selection of the threshold value and therefore may not provide high quality processing of images with different noise levels.

Provided that the edge is detected nearby, the selection of pixels of the enhanced image is made from one of plurality of directionally filtered images thus causing the complete suppression of all image structures that differ by their direction from the detected edge, notwithstanding that those structures can be clearly seen in the original image.

DISCLOSURE OF INVENTION

The object of the claimed invention is to provide a method for enhancing the image sharpness and contrast combined with simultaneous noise suppression.

The said objective is achieved in the image processing method, comprising the presentation of the original image as a matrix of the discreet picture elements (pixels), splitting of the original image into n frequency channels, each channel presented by an image matrix of the same size as the original image, the edge detection and assembling of the output image from said n frequency channels taking the detected edges into account, by splitting of the original image into the low frequency channel and n-1 high frequency channels and edge detection by computation in each of n-1 selected high frequency channels of the correlation between processing pixel and its neighboring pixels, followed by the comparison of said correlation value with that for the corresponding pixels in other high frequency channels and with the threshold value for this channel. Basing on the results of comparison, the weighting coefficients are formed for each pixel of each of n-1 high frequency channels, and the assembly of the output image is made by summing each pixel from the low frequency channel with all products of the corresponding (by their location in the image) pixels of n-1 high frequency channels by their weighting coefficients.

The said objective is also achieved by selection of m of n-1 high frequency channels ($2<m<=n-1$) in such a way that they differ one from another in the direction of principal passing only. Therewithal, the weighting coefficients for any of pixels of any of m high frequency channels is defined basing on the comparison of its correlation value to the threshold value and to the correlation values of the

corresponding (by their location in the image) pixels of other m-1 high frequency channels.

The said objective is also achieved by computation of said correlation as a product of the processing pixel value and the weighted sum of its neighbors, said weights being anisotropic thereat the direction of this anisotropy corresponds to the direction of principal passing of the processing channel.

Furthermore, the threshold value for any of n-1 high frequency channels is determined by analysis of distribution of values, or absolute values, of pixels in this channel. The threshold value may be also determined by analysis of distribution of values, or absolute values, of pixels of the original image.

The claimed as the invention image processing method is characterized by the following features that distinguish it from the most relevant method known in the prior art:

1. while splitting the original image into frequency channels, the low frequency channel and n-1 high frequency channels are selected;
2. the value of correlation between the processing pixel and its neighboring pixels is used to detect edges in the image. More specifically, the value of said correlation is compared to the correlation values for the corresponding (by their location in the image) pixels in other n-1 high frequency channels and to the threshold value for this channel. The weighting coefficients for all pixels of n-1 high frequency channels are generated as a result of this comparison.
3. the output image is assembled by means of summing of each pixel from the low frequency channel and all the corresponding (by their location) pixels from n-1 high frequency channels multiplied by their weighting coefficients.

Concerning the first feature it should be noted that the extraction of the low frequency channel that is not a subject of any processing provides the distortion free reproduction of large-scale objects of the original image in the enhanced image, as these objects are passed through the low frequency channel without any processing. Therewithal the energy of noise passing through the low frequency channel without suppression is low as most of the noise energy is concentrated at high frequencies.

Furthermore, the extraction of the low frequency channel helps reduce the computation efforts needed to find correlation values for n-1 high frequency channels, as the subtraction of the local average value is required to compute correlation. This subtraction is made while extracting (subtracting from the original image) the low frequency channel.

The splitting of the original image into several high frequency channels helps improve, compared to selection of one or two channels, the noise suppression, as a noise associated with pixels of those frequency channels where edges were not found nearby, is prevented from contributing to the enhanced image.

Concerning the second feature it should be noted that edge detection by means of the correlation value between the processing pixel and its neighbors allows to find weak edges on a noisy background as the correlation value is close to zero for the typical noise, thereat the correlation values for adjacent pixels forming the edge are positive and of similar magnitude. This difference in correlation behavior helps achieve the high noise suppression combined with edge emphasis thus increasing the image sharpness and contrast.

The edge detection basing on the correlation between a processing pixel and its neighbors provides a quantitative measure of the edge intensity for each image

pixel. This allows performing the selective emphasis of edges having certain intensity, for example, the weak edges. Furthermore, use of the correlation between the pixel and its neighbors makes the method of the present invention applicable to various types of images, including, for example, color and gray scale images, as well as three-dimensional images.

The third specific feature, namely assembling of the enhanced image by weighted summing of images from all frequency channels, helps to remove completely the effect of the selective noise emphasis. This effect is caused by selection of neighboring pixels from different frequency channels.

Furthermore, the determination of the threshold value by means of analysis of statistical distribution of pixels provides a high quality processing of images with materially different noise magnitudes without changing of parameters.

Furthermore, use of anisotropic frequency channels and anisotropic weights makes the image processing method highly sensitive to weak edges.

BRIEF DESCRIPTION OF DRAWINGS

The claimed invention is illustrated by the drawings of the apparatus that implements the claimed method.

Fig.1 is a block diagram of the apparatus.

The preferred embodiment of the sub-units of said apparatus are shown in more details at Fig. 2 - 5:

Fig.2 is a block diagram of the frequency channel splitting unit (splitting unit).

Fig.3 is a block diagram of the unit for computation of correlations (correlation unit).

Fig.4 is a block diagram of the unit for forming of the weighting coefficients (weighting unit).

Fig.5 is a block diagram of the unit to assemble the output image (assembling unit).

Fig.6 shows an example of the pre-defined channel selection matrixes.

Fig.7 illustrates the operation of the frequency channel splitting unit.

Fig.8 is a graph showing an example of the dependence of the weighting coefficient on the correlation value.

Referring to Fig.1, the apparatus contains the image source 1, the output of said image source connected to the input of the splitting unit 2. The low frequency output 7 of said unit 2 is connected to the input 9 of the assembling unit 5, all other outputs of said splitting unit are connected to the corresponding inputs of the correlation unit 3, said other outputs are also connected to the inputs 10_1 - 10_4 of the assembling unit 5. The outputs of said correlation unit 3 are connected to the corresponding inputs of the weighting unit 4, the outputs of said weighting unit are the inputs 8_1 - 8_4 of the assembling unit 5. Thereat the output of said assembling unit 5 is connected to the input of the memory unit 6, the output of said memory unit is an output of the apparatus.

Fig.2 shows more in details the preferred embodiment of the splitting unit 2. It includes the direct Fourier processor 11, the input of said processor is connected to the output of image source 1, the output of said direct Fourier processor 11 is connected to the first inputs of matrix multiplicators 12_0 - 12_4 The

second inputs of said multiplicators are connected to the corresponding memory units, said memory units hold the pre-defined channel selection matrixes illustrated at Fig.6. Any of the matrix multiplicators 12_0 - 12_4 performs the element-by-element multiplication of matrixes supplied to its two inputs. The outputs of said matrix multiplicators 12_0 - 12_4 are connected to the inputs of the inverse Fourier processors 14_0 - 14_4. The output of the inverse Fourier processor 14_0 is connected to the input 9 of the assembling unit 5, and outputs of the inverse Fourier processors 14_1 - 14_4 are connected to the inputs 10_1 - 10_4 of the assembling unit as well as to the corresponding inputs of the correlation unit 3.

Fig.3 shows more in details the correlation unit 3. The memory unit 15 holds the image of the processing frequency channel. The input of said memory unit is the input of the correlation unit. It is connected also to the input of the noise level measuring unit 20, the output of said unit is connected to the first input of divider 19. The second input of said divider is connected to the output of multiplicator 18. The first input of said multiplicator is connected to the first output of the memory unit 15. Other outputs of said memory unit are connected to the weighting summator 17, the output of said weighting summator is the second input of multiplicator 18. The address input of the memory unit 15 is connected to the address generator 16. The output of divider 19 is the output of the correlation unit.

The noise level measuring unit 20 may be implemented according to the U.S. Patent No. 5,657,401, published on 12.08.97, Int. Class G06K 9/40.

All the memory units are of the random access memory type and they are well known in the art.

The weighting summator 17 may be implemented as eight scalar multiplicators (the number of said multiplicators is equal to the number of adjacent pixels). Any of said scalar multiplicators has two equal inputs and one output. The outputs of all said multiplicators are connected to the inputs of summator, the output of said summator is the output of unit 17. The first inputs of said multiplicators are the inputs of the unit 17 and the pre-defined weighting coefficients are supplied to the second inputs of said multiplicators.

Fig.4 shows the weighting unit 4. The four inputs of the weighting unit 4 are the inputs of four rounding units 23_1 - 23_4, the outputs of said rounding units are connected to the inputs of the address assembling unit 24. The output of said unit 24 is connected to inputs of four look-up tables 25_1 - 25_4. The look-up table is a memory unit that stores the values of the weighting coefficient for any set of the four input correlation values. The outputs of the look-up tables 25_1 - 25_4 are connected to the inputs of the memory units 26_1 - 26_4, said memory units accumulate values of weighting coefficients. The address inputs of the memory units 26_1 - 26_4 are connected to the address generator 27 and the outputs of said memory units are connected to the inputs of summators 28_1 - 28_4 for averaging of weighting coefficients. The outputs of said summators are the outputs of the weighting unit 4.

Fig.5 shows the assembling unit 5. It consists of four multiplicators 29_1 - 29_4 and summator 30. The first inputs 8_1 – 8_4 of said multiplicators are connected to the outputs of the weighting unit 4 and the second inputs 10_1 – 10_4 of said multiplicators are connected to the outputs of the splitting unit 2. The outputs of multiplicators 29_1 – 29_4 are connected to the corresponding inputs of the summator 30 and the input 9 of said summator is connected to the output 7 of the

splitting unit 2. The output of summator 30 is connected to the input of the memory unit 6 that accumulates an enhanced image.

BEST MODE FOR CARRYING OUT THE INVENTION

The apparatus implements the claimed method as it is described hereinafter. Referring to Fig.1, the input image is generated by the image source 1. The MRI unit may be used, for example, as an image source 1. Said MRI unit produces the image of the cross-section of an object, this image being a matrix containing discreet picture elements (pixels). Said image is carried to the input of the splitting unit 2. The operation of the splitting unit 2 is described with a reference to Fig.2 and Fig.7. The input image is transformed to the frequency presentation by the direct Fourier processor 11. Said frequency presentation contains the complete information about the original image and is represented by the matrix of the same size as an input image. This matrix is passed to identical matrix multiplicators

12_0 - 12_4, these matrix multiplicators perform the element-by-element multiplication of the frequency presentation of the original image by pre-defined channel selection matrixes. Said channel selection matrixes are stored in memory units 13_0 - 13_4. Each channel selection matrix contains the multipliers for all spatial frequencies of the frequency image presentation. Fig.6 shows the examples of the channel selection matrixes.

More specifically, as an image is presented by a 2D matrix, its frequency presentation is also a 2D matrix. Fig.6a shows schematically a frequency

presentation matrix. The horizontal and vertical spatial frequencies vary along axes k_x and k_y, respectively.

The zero spatial frequency corresponds to the constant image density. It is located at the crossing point (31) of axes k_x and k_y.

Points 32 and 33 represent the largest spatial frequency in horizontal direction. The examples of images contributing to these points are shown in drawings 34 and 35.

Similarly, the maximal spatial frequency in the vertical direction is located at points 36 and 37; the example of image contributing to these points is illustrated by drawing 38.

The maximal spatial frequencies are located at points 39 - 42. The example of an image contributing to these maximal spatial frequencies is shown in drawing 43.

Medium spatial frequency in horizontal direction is located at point 45. The example of image contributing to this point is shown in drawing 44.

The location of the spatial frequencies in drawings Fig.6(b-f) corresponds to the scheme depicted in Fig.6a.

Fig.6b shows schematically the pre-defined selection matrix for the low frequency channel, said matrix being stored in the memory unit 13_0.

The dark area 46 is filled by the unit values of the matrix elements. This area corresponds to spatial frequencies that pass through the low frequency channel. The white region is filled by the zero values of the matrix elements, therefore the frequencies of the white region do not pass through the low frequency channel.

Fig.6(c-f) show schematically the selection matrixes for four high frequency channels, thereat the same notations as in Fig.6b are used.

It should be noted that the sum of all channel selection matrixes Fig.6(b-f) is the matrix with all elements equal to 1. Therefore all the information from the original image passes through at least one channel.

Referring to Fig.2, each of the matrix multiplicators 12_0 - 12_4 forms on its output the matrix of the corresponding frequency channel in the frequency presentation. The inverse Fourier processors 14_0 - 14_4 transform said matrixes to the coordinate presentation.

The direct Fourier processor 11 and inverse Fourier processors 14_0 - 14_4 may be implemented basing on the Fast Fourier Transform algorithm as described, for example, in: Cooley, J.M., Lewis, P.A.W. and Welch, P.D. (1969) The finite Fourier transform. I.E.E.E. Trans. Audio Electroacoustics AU-17, 2, 77-86.

Fig.7 further illustrates operation of the splitting unit. Fig.7a shows the example of an input image, Fig.7(b-f) show the images formed on outputs of the inverse Fourier processors 14_0 - 14_4, respectively, as a result of processing of the image shown in Fig.7a. The image of a low frequency channel 7b is carried from the output of the Fourier processor 14_0, being the output 7 of the splitting unit 2, to the input 9 of the assembly unit. The images of four high frequency channels are carried from the outputs of the Fourier processors 14_1 – 14_4, being another outputs of the splitting unit 2, to the corresponding inputs of the correlation unit 3 and to the inputs 10_1 – 10_4 of the assembly unit 5.

The further processing of these images will be described on example of one high frequency channel as said processing is identical in all high frequency channels.

Referring to Fig.3, the memory unit 15 stores the partial image of the processing channel. To compute the unnormalized correlation value, the center pixel value 21 and values of its neighboring pixels 22 are sequentially selected from the memory 15. Said values of neighboring pixels pass to the input of weighting summator 17, said summator implements the following operation on pixel values:

$$\mathbf{r} = \sum_{\mathbf{i}=1}^{\mathbf{N}} \mathbf{V_i} \bullet \mathbf{X_i}$$

where N is a number of pixels in neighborhood 22 of the central pixel (preferably N=8), V_i are the pre-defined weighting coefficients (preferably V_i=1/8) and X_i are the pixel values from neighborhood 22. The multiplicator 18 forms a product of the weighted sum of neighboring pixels and the central pixel value. This product is the unnormalized correlation value for the processing pixel. It is compared to the threshold value by dividing by said threshold value (output of the noise level measuring means 20) in divider 19. The result of said division is compared to 1.0 in the weighting unit 4. The processing described herein is repeated for all pixels of the partial image of the processing frequency channel.

The image of this frequency channel passes also to the noise level measuring means 20. The noise level from the output of means 20 is used as a threshold value to normalize correlation values by divider 19. As a result, the matrix containing the correlation values for all pixels of the processing frequency channel is formed on output of the correlation unit 3, said correlation values being normalized by the threshold value for the processing frequency channel.

The correlation values formed by the correlation unit 3 are carried to the weighting unit 4. Referencing to Fig.4, said correlation values for four frequency channels pass to inputs of the rounding means 231 - 23_4. Said rounding means decrease the data precision to 4 or 5 bits.

The four rounded values from outputs of means 23_1 – 23_4, each containing 4 or 5 bits, are assembled into one 16 or 20 bit word by the address assembling unit 24. The formed address is used as an input value for four look up tables 25_1 - 25_4. Each of said look up tables is a memory unit that stores values of the weighting coefficients for any combination of four correlation values in four frequency channels, thereat such combination defines the address formed by the unit 24 in a unique way.

Fig.8 shows the preferred dependence of the weighting coefficient W_i in any of the frequency channels on the correlation value C_i in this channel and correlation values in other three channels, where Δ stands for the threshold value for this frequency channel. The weight W_i depends on the correlation value C_i and maximal correlation value L in other three frequency channels. This dependence is illustrated at Fig.8 by the curves:

curve A for $C_i \geq 0.7$ L,
curve B for $C_i = 0.5$ L,
curve C for $C_i = 0.3$ L,
curve D for $C_i = 0.1$ L and
curve E for $C_i = 0.01$ L.

The memory units 26_1 - 26_4 accumulate values of the weighting coefficients generated by look up tables 25_1 - 25_4. The address generator 27 and summators 28_1 - 28_4 smooth said weighting coefficients in each frequency channel. Said

smoothing is obtained by summing in the summator (for example, 28_1) the center value of the coefficient and its neighboring values being sequentially selected from the memory unit (for example, 26_1) by the address generator 27. The smoothed values of weighting coefficients formed on outputs of summators (for example, 28_1) pass to the outputs of the weighting unit 4.

The operation of the assembling unit is described with a reference to Fig.5. The values of weighting coefficients for four frequency channels pass from the outputs of the unit 4 to the inputs 8_1 - 8_4 of multiplicators 29_1 - 29_4 and the pixel values of the corresponding frequency channels are carried from outputs of the splitting unit 2 to another inputs 10_1 - 10_4 of said multiplicators. The products of said pixel values by the corresponding weighting coefficients generated by multiplicators pass to the inputs of the summator 30. Thereto the corresponding pixel value of the low frequency channel passes to the input 9 of said summator. Thereby the summator 30 calculates the value of the target pixel of the output image, said pixels are accumulated in the memory unit 6.

The embodiment described herein illustrates the method as applied to 2D scalar images. It is understood however that the claimed method may be applied similarly to 3D images. In this case, in the apparatus used to implement the claimed method: the number of frequency channel increases, the 3D Fourier processors are used instead of 2D ones and the number of neighboring pixels (used, for example, to compute a correlation value) is 26 instead of 8.

The claimed method may be applied also to processing of vector images, particularly the color images. Thereat, the 3 components of a vector presenting a pixel value may correspond for example to the intensity of the 3 basic colors for this pixel. In this case, the scalar operations on pixel values, like Fourier transform

and summing, are replaced by the corresponding vector operations as it is known in the art and the correlation is computed as a scalar product of the center pixel value and the weighted vector sum of its neighbors, thereat the vector summator contains as many scalar summators as the number of vector components.

INDUSTRIAL APPLICABILITY

The image processing method according to the invention has the following advantages.

First, use of the correlation between the processing pixel and its neighboring pixels helps detect weak edges against a noisy background. This feature provides high noise suppression in conjunction with the emphasis of weak edges, thus significantly improving the image quality.

Furthermore, use of correlation between the processing pixel and its neighbors makes the method applicable to a wide variety of image types, including color images, gray scale images and 3D images.

Second, the determination of the threshold value by analysis of distribution of pixel values provides a high quality processing of images with the material difference in their noise levels without changing of parameters.

Third, the distortion-free reproduction of the large-scale image structures is achieved due to the separation of the low frequency channel.

CLAIMES

1. The image processing method, comprising the presentation of the original image as a matrix of the discreet picture elements (pixels), splitting of the original image into n frequency channels, each channel presented by an image matrix of the same size as the original image, the detection of edges, and assembling of the output image from said n frequency channels taking the detected edges into account, CHARACTERIZED BY splitting of the original image into the low frequency channel and n-1 high frequency channels and detection of edges by computation in each of n-1 selected high frequency channels for each pixel of the correlation between processing pixel and its neighboring pixels followed by comparison of said correlation value with correlation values for the corresponding (by their location in the image) pixels in other high frequency channels and with the threshold value for this channel; basing on the results of said comparison, the weighting coefficients are formed for each pixel of each of n-1 high frequency channels, and the assembly of the output image is made by summing each pixel from the low frequency channel with all the corresponding (by their location in the image) pixels of n-1 high frequency channels multiplied by their weighting coefficients.

2. The method according to claim 1, CHARACTERIZED BY determination of said weighting coefficient for each pixel of each of n-1 high frequency channels by comparison of the corresponding correlation value to the threshold value.

3. The method according to claim 2, CHARACTERIZED BY the specific dependence of the weighting coefficient on the correlation and threshold values:

- the weighting coefficient takes a minimal value for correlation values that are significantly smaller than the threshold value;

- the weighting coefficient smoothly increases from its minimal value to its maximal value for correlation values that are close to the threshold value;

- the weighting coefficient takes its maximal value for correlation values that are significantly larger than the threshold value.

4. The method according to claim 2, CHARACTERIZED BY the specific dependence of the weighting coefficient on the correlation and threshold values:

- the weighting coefficient takes a minimal value for correlation values that are significantly smaller than the threshold value;

- the weighting coefficient smoothly increases from its minimal value to its maximal value while the correlation value increases to the second threshold value, said second threshold value is equal to the product of the first threshold value by a pre-defined coefficient;

- the weighting coefficient smoothly decreases from its maximal value to its limit value while correlation value is larger than the second threshold value.

5. The method according to claim 1, CHARACTERIZED BY m of said n-1 high frequency channels, where 2<=m<=n-1, being different one from another in the direction of their principal passing only.

6. The method according to claim 5, CHARACTERIZED BY determination of said weighting coefficient for each pixel of each of m high frequency channels by comparison of the corresponding correlation value to the threshold value and to the correlation values for corresponding (by their location in the image) pixels of other m-1 high frequency channels.

7. The method according to claim 1, CHARACTERIZED BY the picture element (pixel) being represented by a scalar value characterizing, for example, the image intensity at the corresponding pixel.

8. The method according to claim 7, CHARACTERIZED BY computation of said correlation value for each pixel by multiplication of said pixel value by the weighted sum of its neighboring pixels.

9. The method according to claims 8 and 5, CHARACTERIZED BY use of anisotropic weights for computation of said weighted sum of the neighboring pixels, thereat the direction of said anisotropy corresponds to the direction of principal passing for the processing frequency channel.

10. The method according to claim 7, CHARACTERIZED BY determination of said threshold value for each of said n-1 high frequency channels by analysis of distribution of pixel values in an image of the processing frequency channel.

11. The method according to claim 7, CHARACTERIZED BY determination of said threshold value for all said frequency channels by analysis of distribution of pixel values of the original image.

12. The method according to claim 1, CHARACTERIZED BY the picture element (pixel) being represented by a vector, components of said vector characterizing, for example, the intensity of the basic colors (red, green and blue) at the corresponding pixel.

13. The method according to claim 12, CHARACTERIZED BY computation of said correlation value for each pixel as a scalar product of said pixel vector by the weighted sum of vectors representing its neighboring pixels.

14. The method according to claims 13 and 5, CHARACTERIZED BY use of anisotropic weights for computation of said weighted sum of the neighboring pixels, thereat the direction of said anisotropy corresponds to the direction of principal passing for the processing frequency channel.

15. The method according to claim 12, CHARACTERIZED BY determination of said threshold value for each of said n-1 high frequency channels by analysis of distribution of absolute values of vectors representing pixels of an image of the processing frequency channel.

16. The method according to claim 12, CHARACTERIZED BY determination of said threshold values for all high frequency channels by analysis of distribution of absolute values of vectors representing pixel values of the original image.

17. The method according to claim 1, CHARACTERIZED BY smoothing of the correlation values for several neighboring pixels before computation of the weighting coefficients, said smoothing being implemented at least in one of n-1 high frequency channels.

18. The method according to claim 17, CHARACTERIZED BY non linear transformation of the correlation values prior to the smoothing of the correlation values, said non linear transformation remains unchanged the values that are smaller or close to the threshold value, and decreases correlation values that are significantly larger than the threshold value.

19. The method according to claim 1, CHARACTERIZED BY smoothing of the weighting coefficients over several neighboring pixels, said smoothing being implemented at least in one of n-1 high frequency channels.

20. The method according to claim 1 CHARACTERIZED BY the input image being p dimensional matrix of picture elements, where p is greater or equal to 3.

21. The method according to claim 1, CHARACTERIZED BY use of different threshold values for different parts of the image, said different threshold values being used to form the weighting coefficients at least in one of n-1 high frequency channels.

22. The method according to claims 7 and 21, CHARACTERIZED BY determination of said threshold values for different parts of the image and different high frequency channels by the analysis of distribution of pixel values in the corresponding part of the image of the corresponding frequency channel.

23. The method according to claims 12 and 21, CHARACTERIZED BY determination of said threshold values for different parts of the image and different frequency channels by the analysis of distribution of absolute values of vectors representing pixels in the corresponding part of the image of the corresponding frequency channel.

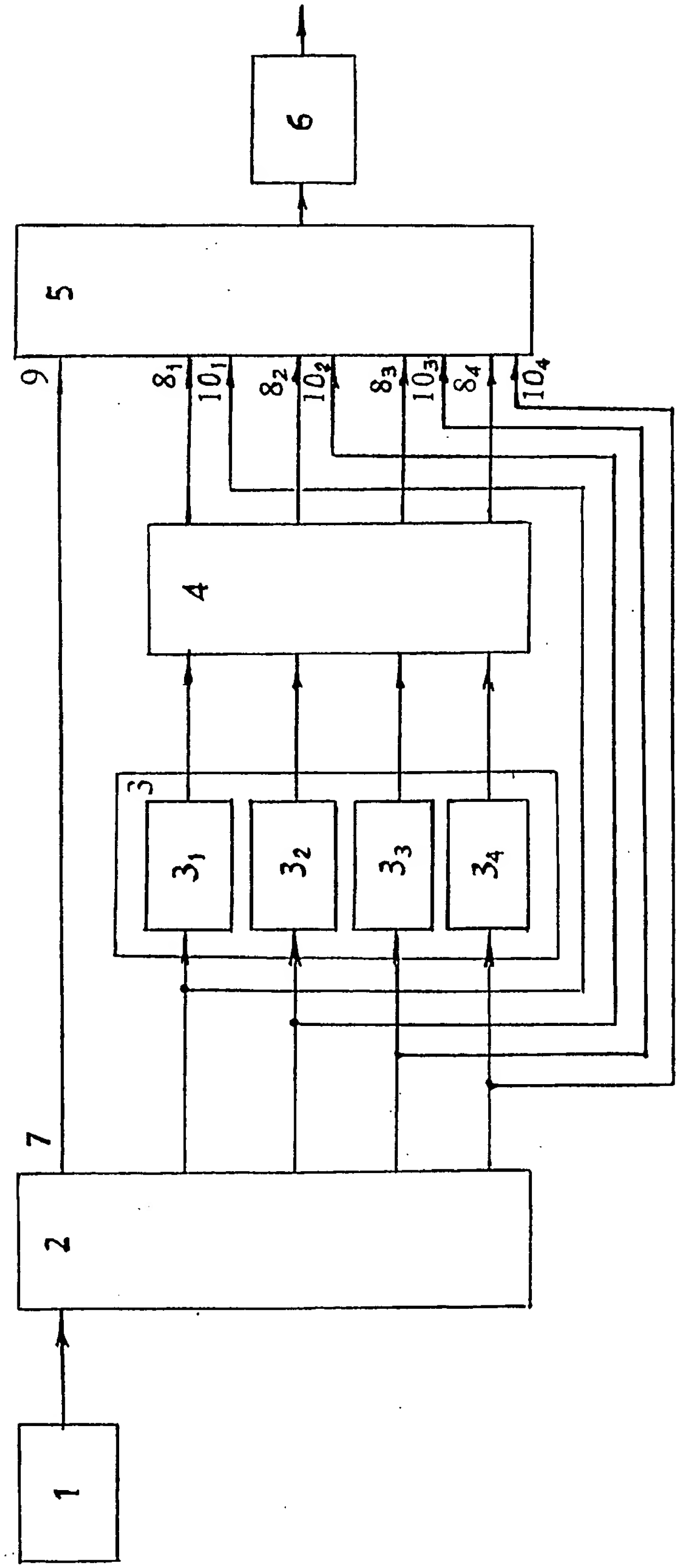


Fig.1

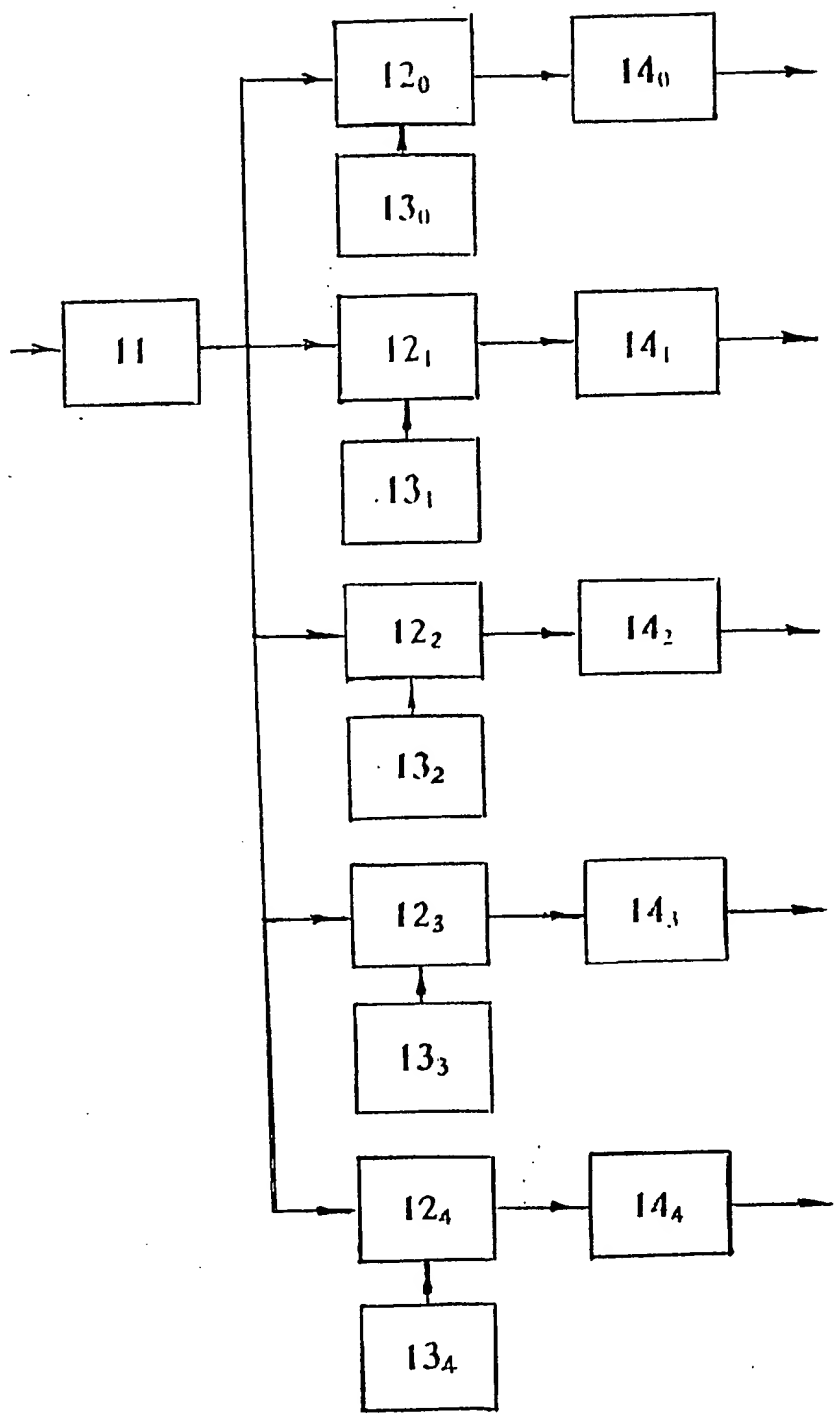


Fig.2

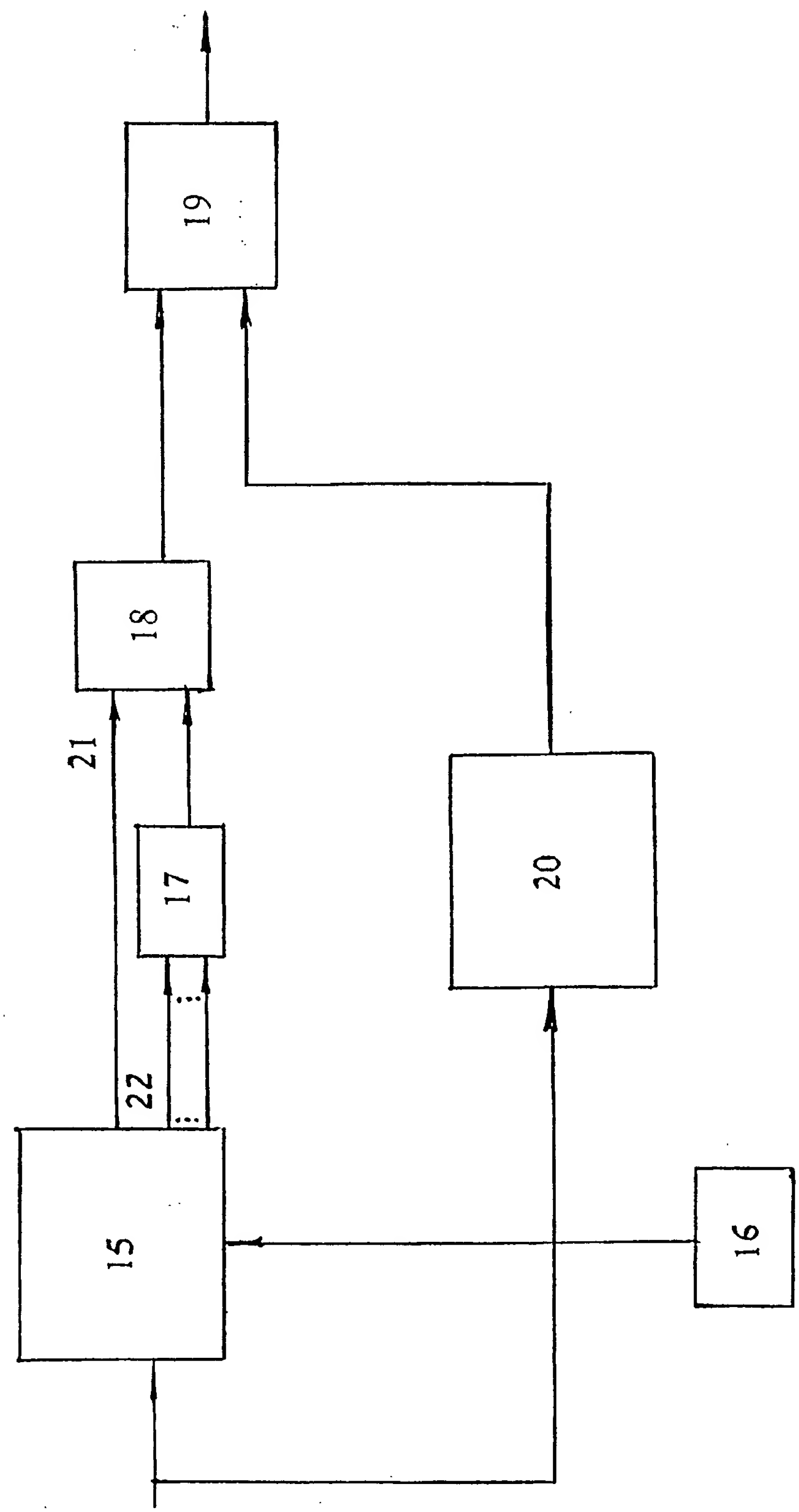


Fig.3

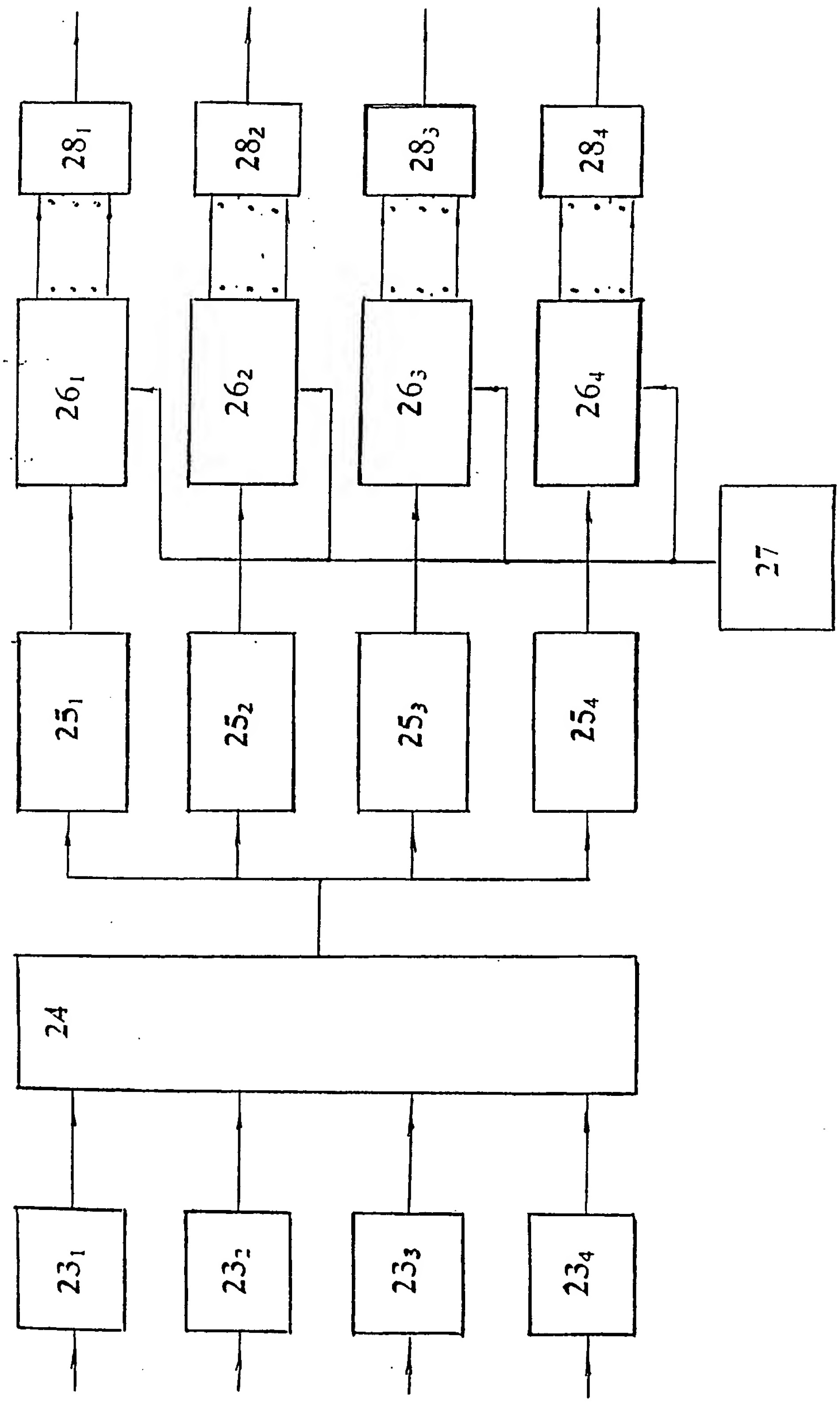

23₁
23₂
23₃
23₄
24
25₁
25₂
25₃
25₄
26₁
26₂
26₃
26₄
27
28₁
28₂
28₃
28₄

Fig.4

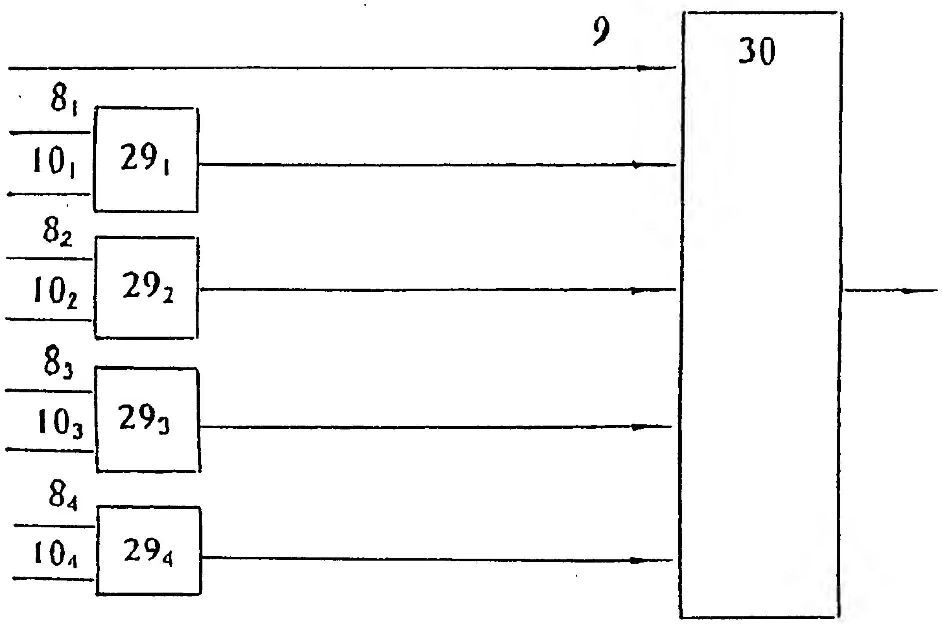


Fig.5

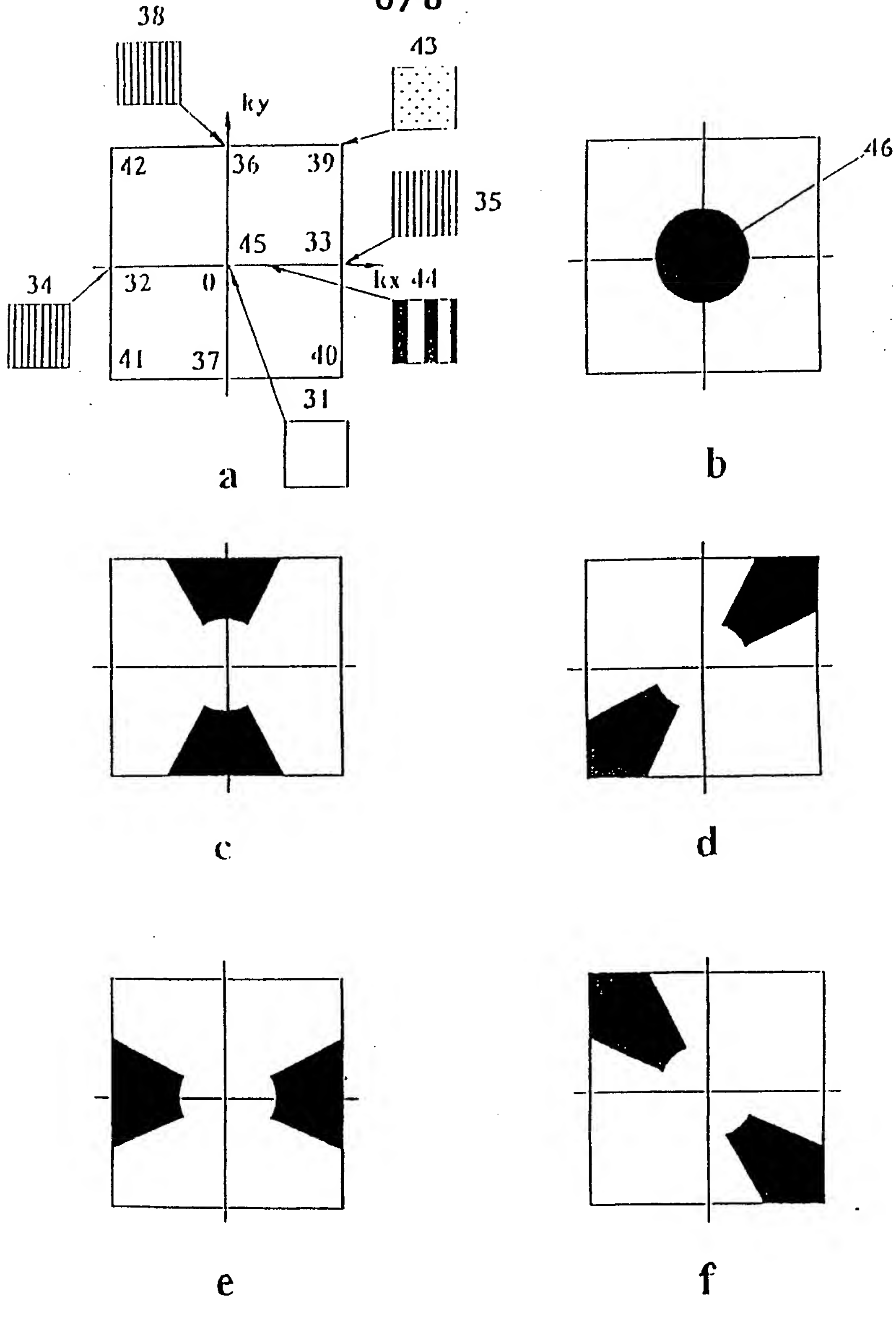


Fig.6

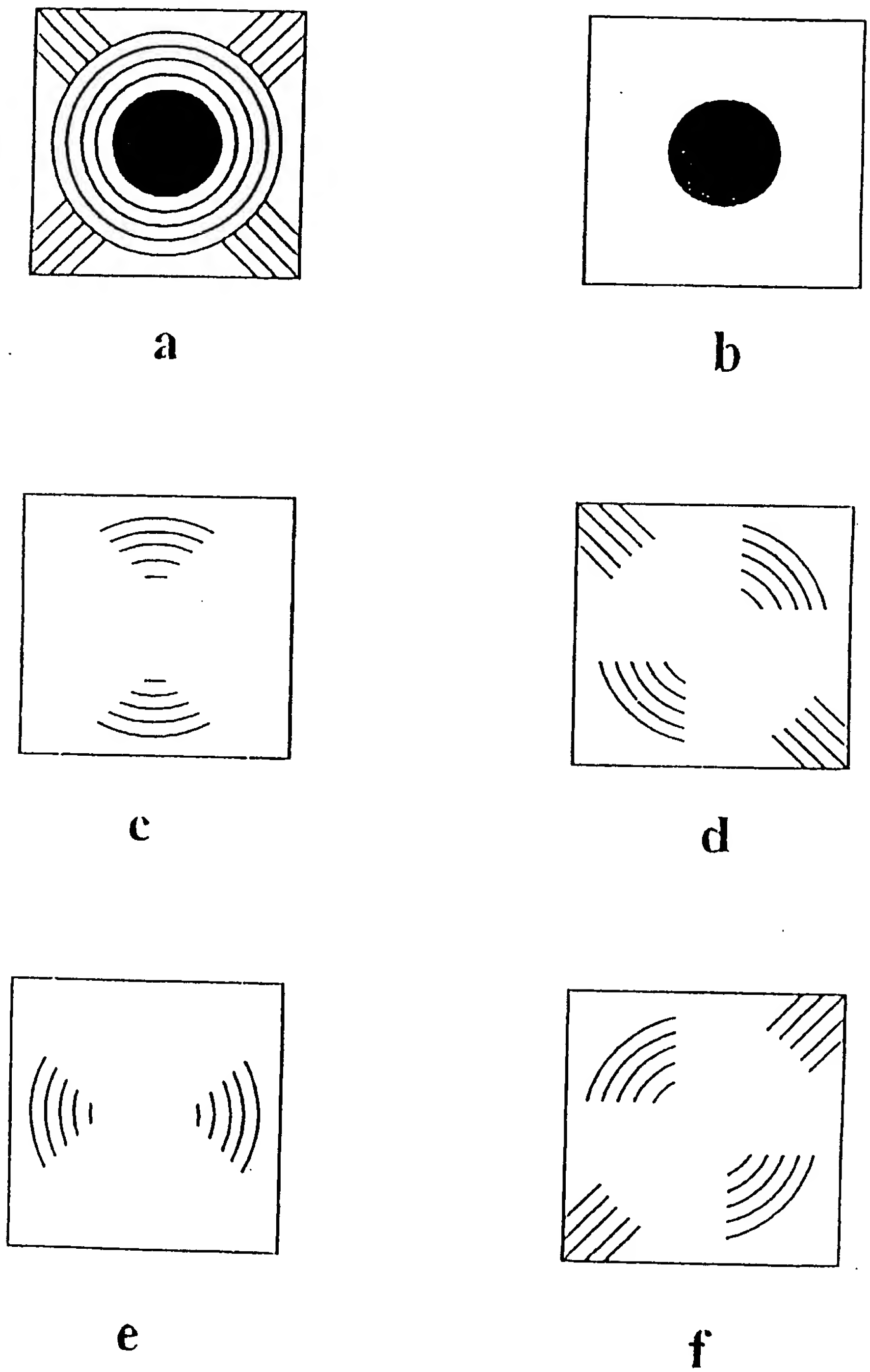


Fig.7

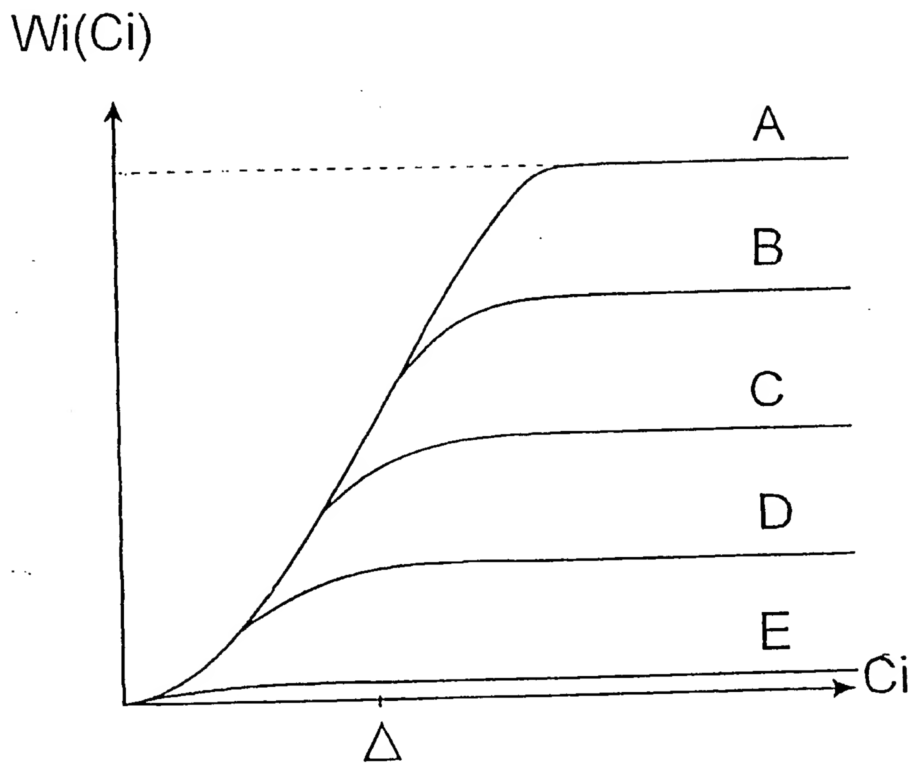


Fig.8

IMAGE PROCESSING METHOD

CROSS-REFERENCES TO RELATED APPLICATIONS

The present application is a continuation-in-part of PCT application WO 00/14684 claiming priority from application 98116546 filed on 3 September 1998 in Russian Federation, which PCT application is by reference incorporated herein in its entirety.

FIELD OF THE INVENTION

The present invention relates to the automatics and computation techniques and, more particularly, to methods of the preliminary image processing for sharpening and contrast enhancement.

DESCRIPTION OF THE RELATED ART

One of the methods known in the prior art is described in the Russian Patent No.2015561, published on 16.04.91, Int. Class G06K 9/40. According to this invention, the image correction is made basing on the analysis of the original image at the processed pixel and the local average value over some neighborhood of this pixel.

The method of that patent smoothes the original image, thus producing the smoothed image containing the low frequency components presenting the image background. Then the smoothed image is subtracted from the original one producing the second image containing high frequency components without background, said second image is then emphasized and added to the smoothed image.

The disadvantage of this method is that it emphasizes not only the useful signal but also the noise containing in high frequency image components, thus degrading the quality of the enhanced image.

The method according to U.S. Patent No. 5,038,388, published on 06.08.91, Int. Class G06K 9/40 smoothes the original image and subtracts the smoothed image from the original one thus producing the second image containing high frequency image components only. The

second image is then adaptively emphasized so that the larger is a difference between the processed pixels and their neighborhood, the higher are their scaling factors. The output image is produced by adding the adaptively emphasized second image to the original image, thus sharpening the image without the noise amplification.

The solution disclosed in this patent does not provide any noise suppression as this method can only emphasize the high frequency image components that may contain a noise.

Furthermore, the disadvantage of this method known in the art is that it fails to improve considerably the sharpness of weak edges as such enhancement requires to emphasize high frequency image components in the regions where a difference between the processed pixel and its neighborhood is comparable to a noise level. Therefore, the edge enhancement in such regions causes the noise emphasis.

According to the image processing method disclosed in U.S. Patent No. 5,381,490, published on 10.01.95, Int. Class G06K 9/40, the largest difference Δ between the processed pixel and its nearest neighbors is calculated. Depending on the magnitude of this difference, one of the three processing modes is selected:

- edge enhancement by means of emphasis of the high frequency image components if $\Delta > T_1$, T_1 presenting the first pre-defined threshold value;
- reproduction of the original image, if $T_2 < \Delta < T_1$, where T_2 stands for the second pre-defined threshold value;
- image smoothing to suppress noise, if $\Delta < T_2$.

The first disadvantage of this method is that it may emphasize the noise selectively if the difference Δ varies around any of the threshold values for some neighboring pixels thus transforming small differences between neighboring pixels into larger ones by involving different processing modes for these neighboring pixels.

Furthermore, this method fails to provide quality enhancement of images with different noise magnitudes without tuning as the threshold values T_1 and T_2 are not selected adaptively.

Another approach to the noise suppression in images is described in U.S. Patent 5,563,963, published on 08.10.96, Int. Class G06K 9/40. The method of this patent operates by selecting a plurality of groups of neighbors for each pixel of the original image, each group being a square containing N x N pixels, N varying for example from 2 to 21. The processed pixel may be located at any position inside this square group of pixels. The least square best fit plane (the planar approximation) is then used to approximate pixel values in each of selected pixel groups, and the new value for the processed pixel and the goodness of fit are computed based on the approximation for each group.

The target pixel of an enhanced image is produced by the weighted summing of all the new pixel values, thereat the higher is the goodness of fit for a group, the higher is the weight of this group.

The disadvantage of this method is that it fails to enhance edges as this method provides the noise smoothing only. Furthermore, this method requires substantial computation power to build least square approximations by hundreds of groups for each of hundreds of thousands of pixels.

The method disclosed in U.S. Patent 5,739,922, published on 14.04.98, Int. Classes G06K 9/40, H04N 1/40, operates by splitting an original color image into three isotropic frequency channels: low frequency image components (LF), medium frequency components (MF), and high frequency components (HF). Adaptive emphasis of the HF components and adaptive suppression of the MF components is then carried out, thereat the higher is the correlation between at least two of three basic image colors, the higher are multipliers for HF and MF image components. The enhanced image is obtained by summing the LF image components with the adaptively suppressed MF components and the adaptively emphasized HF image components.

The image processing method and apparatus described in said patent may have limited application as they are suitable for color images only since it is the correlation between color components only that is used for carrying out the image processing.

Furthermore, the noise suppression according to this invention is significantly limited, as the HF image components, that also contain noise, may be emphasized only and the noise suppression in MF image components is limited because no directional splitting of the original image is used.

No edge detection and enhancement can be obtained by this method as the isotropic frequency channels are used.

All these disadvantages degrade the quality of enhanced images.

The most relevant image processing method is described in U.S. Patent No. 5,351,305, published on 27.09.94, Int. Class G06K 9/40. According to this patent, a plurality of directionally filtered images is obtained from an original image by applying directional filters in a frequency domain. An enhanced image is then formed by selecting each target pixel either from a directionally filtered image, if a contrast edge is detected nearby the processed pixel, or from the original image otherwise. Thereat, the contrast edge is detected nearby the processed pixel by generating a standard deviation image and by producing an eigenvector description of this image. The eigenvector length is compared to a pre-determined threshold value to detect the edge.

The target pixel is equal to the corresponding pixel of the original image, if the edge was not detected nearby. Otherwise, the target pixel is selected from an image filtered with the most nearly corresponding direction of filtering.

While detecting edges, the eigenvector length may vary around the threshold value for several adjacent pixels. Whereby, the neighboring pixels of the enhanced image are selected from different images (the original image and directionally filtered image) thus causing the selective noise emphasis. This emphasis degrades the enhanced image quality.

Furthermore, original images may differ in their noise levels thus requiring different threshold values. The method does not include adaptive selection of the threshold value and, therefore, may not provide high quality processing of images with different noise levels.

Provided that the edge is detected nearby, the selection of pixels of the enhanced image is made from one of the plurality of directionally filtered images thus causing the complete suppression of all image structures that differ by their direction from the detected edge, notwithstanding that those structures can be clearly seen in the original image.

SUMMARY OF THE INVENTION

The object of the claimed invention is to provide an improved method for enhancing the image sharpness and contrast combined with simultaneous noise suppression.

It is an additional object of the present invention to provide such a method for enhancing the image sharpness and contrast combined with simultaneous noise suppression that is applicable to multi-dimensional images, scalar and vector images.

Multi-dimensional images are represented by a matrix of picture elements with dimension larger than 2. The most common case is a three-dimensional image (3D image). The last consists of a number of slices and each slice is a plain image.

Each pixel of a vector image is represented by a vector (having more than one component) rather than a scalar value. For example, 3 vector components may represent intensity of 3 basic colors (red, green and blue) in a color image. Another application that requires processing the vector images is Magnetic Resonance Imaging (MRI). MRI units produce complex images, each pixel being represented by real and imaginary parts. It is beneficial to process the complex images rather than to first take the magnitude value and then process scalar images.

The method of the present invention for simultaneous sharpness enhancement and noise reduction is comprised of the steps of: providing an original image as a matrix of discreet picture elements (pixels); splitting the original image into a low frequency channel and n-1 high frequency channels; detecting edges; and assembling an output image from the n frequency channels taking the detected edges into account.

The number n-1 of the high frequency channels depends on the image properties and required a degree of the image enhancement. The higher is n-1, the higher is sensitivity of the method to weak edges and the higher is noise suppression. Typically, n-1 is in the range of 4 ... 12.

The high frequency channels may differ from one another by: (i) the direction of their principal passing (anisotropic frequency channels) and (ii) the absolute spatial frequency range (isotropic frequency channels). In the first case, edges are grouped into different high frequency channels based on edge direction, so that edges in a particular high frequency channel are characterized by a similar direction. In the second case, the edges and other image structures are grouped into different high frequency channels based on a typical size of the structure (width of the edge), so that edges and structures in a particular high frequency channel are characterized by the similar size. A combination of both splitting methods may be used.

To determine if the processed pixel belongs to some edge, correlation between a processed pixel value and values of its neighboring pixels is computed in all of the high frequency channels. The method to compute correlation values is dependent on the pixel presentation in the original image, as well as on the properties of the processed high frequency channel. In the simplest case of the scalar pixels and an isotropic high frequency channel, the correlation value is equal to the product of the processed pixel value by the sum of its neighbors. While processing the anisotropic high frequency channels, it is preferable to use anisotropic weights when computing the sum of neighbors, whereat these weights emphasize values of those pixels that are shifted along the direction of the principal passing from the processed pixel. To calculate the correlation value for vector images, the scalar product of the processed pixel value by the (weighted) sum of its neighbors may be used. For example, the correlation value for the complex image is defined as:

$$C = V_0 \, \mathrm{conj}(R).$$

Here V_0 is the value of the processed pixel and conj(R) is the complex conjugate of the (weighted) sum of its neighbors.

The resulting n-1 correlation values (or some selected subset of these values) are compared to one another and to their respective threshold values. These threshold values are selected based on the statistics of the image of the processed high frequency channels and represent typical noise levels. The threshold values for vector images may be selected based on the distribution of absolute values of vectors representing pixels of the image of the processed high frequency channels. Alternatively, all threshold values are derived from the input image statistics.

Based on the results of comparison of the correlation values and threshold values, the weighting coefficients are formed for all pixels of all n-1 high frequency channels. The following basic cases may be considered:

- For a particular high frequency channel, the correlation value appears to be smaller than its respective threshold value. Then the processed pixel in this high frequency channel represents a noise contribution. Therefore, a small weighting coefficient is assigned to the processed pixel in this high frequency channel thus providing the noise suppression.
- For a particular high frequency channel, the correlation value appears to be higher than the threshold value, as well as all correlation values for corresponding (by their location in the image) pixels in all other high frequency channels (or the selected subset of high frequency channels). Then, the processed pixel belongs to an edge region and the edge direction matches the direction of the principal passing of this particular frequency channel. Therefore, a large weighting coefficient is assigned to the processed pixel in this particular high frequency channel thus providing edge enhancement.
- Correlation values in all high frequency channels (or in a selected subset of channels) are larger than their respective threshold values and they are similar in magnitude. Then, the processed pixel belongs to some structure that is not an edge. Therefore, medium weighting coefficients are assigned to all corresponding (by their location in the image) pixels in high frequency channels thus providing non-distorted reproduction of structures of the original image.

Summarizing, the weighting coefficient for the processed pixel of some high frequency channel is a function of correlation values for all corresponding (by their location in the image) pixels of high frequency channels and the threshold value of this high frequency channel. This function may be implemented differently depending on the properties of the original images and enhancement goals. Particularly, this function may be dependent on some subset of correlation values. In the simplest case, the weighting coefficient for a high frequency channel may be dependent on the correlation and threshold values of this high frequency channel only. Then, low values of the weighting coefficient are selected for those pixels that have correlation values smaller than the threshold value of this high frequency channel. Pixels that have correlation values significantly higher than the threshold value get high weighting coefficients. The smooth transition between these two cases is preferably implemented for the correlation values comparable to the threshold value.

Assembling the output image is made by summing each pixel from the low frequency channel with all products of the corresponding (by their location in the image) pixels of n-1 high frequency channels by their respective weighting coefficients. The use of these weighting coefficients to control contributions of pixels from different high frequency channels, as an alternative to selecting a single pixel value from one of the plurality of frequency channels, allows smooth switching from the noise suppression achieved by low values of weighting coefficients to the edge enhancement obtained with high values of these coefficients.

The image processing method claimed as the invention is characterized by the following features that distinguish it from the most relevant method known in the prior art:

1. while splitting the original image into n frequency channels, a low frequency channel and n-1 high frequency channels are selected;
2. the value of correlation between the processed pixel and its neighboring pixels is used to detect edges in the image.

3. the output image is assembled by means of summing each pixel from the low frequency channel and all the corresponding (by their location) pixels from n-1 high frequency channels multiplied by their respective weighting coefficients.

Concerning the first feature, it should be noted that the extraction of the low frequency channel that is not a subject of any processing provides the distortion-free reproduction of large-scale structures of the original image in the enhanced image, as these structures are passed through the low frequency channel without any processing. Therewithal, the energy of noise passing through the low frequency channel without suppression is inherently low as most of the noise energy is concentrated at high frequencies.

Furthermore, the extraction of the low frequency channel helps reduce the computation power needed to find correlation values for n-1 high frequency channels as the subtraction of the local average value is required to compute correlation. This subtraction is made while extracting (subtracting from the original image) the low frequency channel.

Splitting the original image into several high frequency channels helps improve noise suppression (compared to selection of one or two channels) as the noise associated with pixels of those frequency channels where edges were not found nearby is prevented from contributing to the enhanced image.

As far as the second feature is concerned, it should be noted that the edge detection by means of the correlation value between the processed pixel and its neighbors allows to find weak edges against a noisy background as the correlation value is close to zero for a typical noise, whereby the correlation values for adjacent pixels forming the edge are positive and of the similar magnitude. This difference in correlation behavior helps achieve high noise suppression combined with edge emphasis, thus significantly improving the image quality. The edge detection based on the correlation between a processed pixel and its neighbors makes the method of the present invention applicable to various types of images, including color, gray scale and complex images, as well as multi-dimensional images. Furthermore, the use of this correlation provides a quantitative measure of the edge intensity for each image

pixel. This feature allows performing the selective emphasis of edges characterized by certain intensity, for example, weak edges.

The third specific feature, namely assembling the enhanced image by weighted summing images from all frequency channels, helps remove completely the effect of the selective noise emphasis. This effect is caused by the selection of neighboring pixels from different frequency channels.

Furthermore, the determination of the threshold value by means of analysis of statistical distribution of pixels provides a high quality processing of images with materially different noise magnitudes without changing parameters.

Furthermore, use of anisotropic frequency channels and anisotropic weights makes the image processing method highly sensitive to weak edges.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages of the invention will appear from the following description in which a preferred embodiment has been set forth in detail, in conjunction with the accompanying drawings of the apparatus that implements the claimed method, where

Figure 1 is a block diagram of the apparatus.

The preferred embodiment of the sub-units of said apparatus is shown in more detail in Figures 2 – 5, where

Figure 2 is a block diagram of a frequency channel splitting unit.

Figure 3 is a block diagram of one channel of a unit for computation of correlation values (a correlation unit).

Figure 4 is a block diagram of a unit to form the weighting coefficients (a weighting unit).

Figure 5 is a block diagram of a unit to assemble the output image (an assembling unit).

Figure 6 shows an example of pre-defined channel selection matrixes.

Figure 7 illustrates the operation of the frequency channel splitting unit.

Figure 8 is a graph showing an example of the dependence of the weighting coefficient on the correlation value.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to Figure 1, the apparatus contains an image source 1, an output of the image source being connected to an input of a splitting unit 2. A low frequency output 7 of the unit 2 is connected to an input 9 of an assembling unit 5, whereas all other outputs of the splitting unit 2 are connected to corresponding inputs of a correlation unit 3. These other outputs are also connected to inputs 10_1 - 10_4 of the assembling unit 5. Outputs of the correlation unit 3 are connected to corresponding inputs of a weighting unit 4, its outputs being inputs 8_1 - 8_4 of the assembling unit 5. Thereat, an output of the assembling unit 5 is connected to an input of a memory unit 6, an output of this memory unit being an output of the apparatus.

Figure 2 shows the preferred embodiment of the splitting unit 2 in more detail. The unit includes a direct Fourier processor 11, an input of said processor being connected to the output of the image source 1. An output of the direct Fourier processor 11 is connected to first inputs of matrix multiplicators 12_0 - 12_4. Second inputs of the multiplicators are connected to corresponding memory units 13_0 - 13_4, these memory units holding pre-defined channel selection matrixes shown in Figure 6. Any of the matrix multiplicators 12_0 - 12_4 performs element-by-element multiplication of matrixes supplied to its two inputs. Outputs of the matrix multiplicators 12_0 - 12_4 are connected to inputs of the inverse Fourier processors 14_0 - 14_4. An output of the inverse Fourier processor 14_0 is connected to the input 9 of the assembling unit 5, and outputs of the inverse Fourier processors 14_1 - 14_4 are connected to the

inputs 10_1 - 10_4 of the assembling unit 5, as well as to the corresponding inputs of the correlation unit 3.

Figure 3 shows in more detail one channel of the correlation unit 3. A memory unit 15 holds the image of the respective frequency channel. An input of this memory unit is one of the inputs to the correlation unit 3. The input is also connected to an input of a noise level-measuring unit 20, an output of the unit 20 being connected to a first input of a divider 19. A second input of this divider is connected to an output of a multiplicator 18, whose first input is connected to a first output of the memory unit 15. Other outputs of the unit 15 are connected to a weighting adder 17. An output of the adder 17 is a second input of the multiplicator 18. An address input of the memory unit 15 is connected to an address generator 16. An output of the divider 19 is the output of the channel of the correlation unit 3.

The noise level measuring unit 20 may be implemented according to the U.S. Patent No. 5,657,401, published on 12.08.97, Int. Class G06K 9/40, which is incorporated herein by reference.

All of the memory units are of a random access memory type, and DIMM PC133 128 Mb memory modules manufactured by IBM, or other similar ones well known in the art can be used for that purpose.

The weighting adder 17 may be implemented as eight scalar multiplicators and an adder (the number of the multiplicators is equal to the number of pixels in the neighborhood 22 of the processed pixel). Any of these scalar multiplicators has two functionally identical inputs and one output. The outputs of all scalar multiplicators are connected to inputs of the adder, and its output is the output of unit 17. First inputs of the scalar multiplicators are the inputs of the unit 17 and pre-defined weighting coefficients are supplied to second inputs of the scalar multiplicators.

Figure 4 shows the weighting unit 4. The four inputs of the weighting unit 4 are inputs of four rounding units 23_1 - 23_4, outputs of the rounding units are connected to inputs of an address assembling unit 24. An output of the unit 24 is connected to inputs of four look-up tables 25_1 - 25_4. The look-up table is a memory unit that stores the values of a weighting

coefficient for any set of the four input correlation values. Outputs of the look-up tables 25_1 - 25_4 are connected to inputs of memory units 26_1 - 26_4, which accumulate values of weighting coefficients. Address inputs of the memory units 26_1 - 26_4 are connected to an address generator 27, whereas outputs of the memory units are connected to inputs of adders 28_1 - 28_4 for averaging weighting coefficients. Outputs of the adders are the outputs of the weighting unit 4.

Figure 5 shows the assembling unit 5. It consists of four multiplicators 29_1 - 29_4 and an adder 30. First inputs $8_1 - 8_4$ of said multiplicators are connected to the outputs of the weighting unit 4, and second inputs $10_1 - 10_4$ of said multiplicators are connected to the outputs of the splitting unit 2. Outputs of multiplicators $29_1 - 29_4$ are connected to corresponding inputs of the adder 30 and an input 9 of the adder is connected to the output 7 of the splitting unit 2. An output of the adder 30 is the output of the assembling unit 5, and it is connected to the input of the memory unit 6 that accumulates an enhanced image.

All of the above blocks in Figures 1-5 constituting the apparatus realizing the method of the present invention may virtually exist in a regular personal computer and be assumingly singled out of it to define a specific hardware configuration of the apparatus.

The apparatus implements the claimed method as it is described hereinafter in more detail. Referring to Figure 1, an input image is generated by the image source 1. The Magnetic Resonance Imaging (MRI) unit may be used, for example, as the image source 1. This MRI unit produces an image of some cross-section of an object, this image being a matrix of discreet picture elements (pixels). The image is carried to the input of the splitting unit 2. The operation of the splitting unit 2 is described with a reference to Figures 2, 6 and 7. The input image is transformed to the frequency presentation by the direct Fourier processor 11. This frequency presentation contains complete information about the original image and is represented by the matrix of the same size as the input image. The matrix is passed to the identical matrix multiplicators 12_0 - 12_4. They perform element-by-element multiplication of the frequency presentation of the original image by pre-defined channel selection matrixes. The channel selection matrixes are stored in the memory units 13_0 - 13_4. Each channel

selection matrix contains multipliers for all spatial frequencies of the frequency image presentation. Figure 6 shows examples of the channel selection matrixes.

More specifically, as the image is presented by a 2D matrix, its frequency presentation is also a 2D matrix. Figure 6a shows schematically a frequency presentation matrix. The horizontal and vertical spatial frequencies vary along axes k_x and k_y, respectively.

The zero spatial frequency corresponds to the constant image density. It is located at the crossing point (31) of axes k_x and k_y.

Points 32 and 33 represent the largest spatial frequency in a horizontal direction. The examples of images contributing to these frequencies are shown in drawings 34 and 35.

Similarly, the maximal spatial frequency in a vertical direction is located at points 36 and 37; the example of image contributing to these frequencies is illustrated by drawing 38.

The maximal spatial frequencies are located at points 39 - 42. The example of an image contributing to these maximal spatial frequencies is shown in drawing 43.

Medium spatial frequency in the horizontal direction is located at point 45. The example of image contributing to this frequency is shown in drawing 44.

The location of the spatial frequencies in drawings Figures 6(b-f) corresponds to the scheme depicted in Figure 6a.

Figure 6b shows schematically the predefined selection matrix for the low frequency channel, this matrix being stored in the memory unit 13_0.

The dark area 46 is filled by the unit values of the matrix elements. This area corresponds to spatial frequencies that pass through the low frequency channel. The white region is filled by the zero values of the matrix elements, therefore the frequencies of the white region do not pass through the low frequency channel.

Figures 6(c-f) show schematically the selection matrixes for four high frequency channels, the same notations as in Figure 6b being used thereat.

It should be noted that the sum of all channel selection matrixes Figures 6(b-f) is the matrix with all elements equal to 1. Therefore, all the information from the original image passes through at least one channel.

Referring now to Figure 2, each of the matrix multiplicators 12_0 - 12_4 forms on its output the matrix of the corresponding frequency channel in the frequency presentation. The inverse Fourier processors 14_0 - 14_4 transform these matrixes to the coordinate presentation.

The direct Fourier processor 11 and inverse Fourier processors 14_0 - 14_4 may be implemented based on the Fast Fourier Transform algorithm as described, for example, in: Cooley, J.M., Lewis, P.A.W. and Welch, P.D. *The Finite Fourier Transform* IEEE Trans. Audio Electroacoustics AU-17, 2, 77-86, 1969.

Figure 7 further illustrates operation of the splitting unit. Figure 7a shows the example of an input image, Figures 7(b-f) show the images formed on the outputs of the inverse Fourier processors 14_0 - 14_4, respectively, as a result of processing of the image shown in Fig.7a. The image of a low frequency channel 7b is carried from the output of the Fourier processor 14_0, being the output 7 of the splitting unit 2, to the input 9 of the assembly unit 5. The images of four high frequency channels are carried from the outputs of the Fourier processors $14_1 - 14_4$, being another outputs of the splitting unit 2, to the corresponding inputs of the correlation unit 3 and to the inputs $10_1 - 10_4$ of the assembly unit 5.

The further processing of these images will be described by the example of the first high frequency channel as this processing is identical in all high frequency channels.

Referring to Figure 3, the memory unit 15 stores the partial image of the processed channel. To compute the unnormalized correlation value, the processed pixel value 21 and values of pixels from its neighborhood 22 are sequentially selected from the memory 15. These values of pixels from neighborhood 22 pass to the input of weighting adder 17. The adder 17 implements the following operation on pixel values:

$$r = \sum_{i=1}^{N} V_i X_i$$

where N is a number of pixels in neighborhood 22 of the processed pixel (preferably N=8), V_i are the pre-defined weights (preferably V_i=1/8) and X_i are the values of pixels from neighborhood 22.

Alternatively, anisotropic weights V_i can be used. Anisotropic weight V_i is dependent on the direction of offset of a neighbor pixel X_i from the processed pixel. This offset may be characterized by coordinates of a neighbor pixel with respect to the processed pixel expressed in number of pixels. Preferably, neighborhood 22 includes 8 pixels: (1,0), (0,1), (-1,0), (0,-1) and (1,1), (-1,1), (-1,-1), (1,-1). Their respective offset directions are: 0°, 90°, 180°, 270° and 45°, 135°, 225°, 315°. The directions of principal passing for four high frequency channels (Figures 7 c, d, e, f) are: 0°, 135°, 90° and 45°, respectively. Therefore, for channel Figure 7c the weights V_i for pixels (1,0) and (-1,0) are higher than weights V_i for other pixels, thus providing emphasis of pixel values that were shifted along the direction of principal passing. Pixels (-1,1) and (1,-1) get higher weights in channel Figure 7d, etc.

The multiplicator 18 forms a product of the weighted sum of neighboring pixels and the processed pixel value. This product is the unnormalized correlation value for the processed pixel. It is compared to the threshold value by dividing by this threshold value (output of the noise level measuring means 20) in divider 19. The result of this division is compared to 1.0 in the weighting unit 4. The processing described herein is repeated for all of the pixels of the partial image of the processed frequency channel.

The image of the first frequency channel passes also to the noise level measuring means 20. The noise level from the output of the means 20 is used as a threshold value to normalize correlation values by the divider 19. As a result, the matrix containing the correlation values for all of the pixels of the processed frequency channel is formed on the output of the correlation unit 3, these correlation values being normalized by the threshold value for the processed frequency channel.

The correlation values formed by the correlation unit 3 are carried to the weighting unit 4. Referencing now to Figure 4, those correlation values for four frequency channels pass to inputs of the rounding means $23_1 - 23_4$. These rounding means decrease the data precision to 4 or 5 bits.

The four rounded values from outputs of the means $23_1 - 23_4$, each containing 4 or 5 bits, are assembled into one 16- or 20-bit word by the address assembling unit 24. The address formed thereby is used as an input value for the four look-up tables 25_1 - 25_4. Each of them is a memory unit that stores values of the weighting coefficients for any combination of four correlation values in four frequency channels, such combination defining thereat the address formed by the unit 24 in a unique way.

Let W_i be the weighting coefficient read out of the look up table 25_1 for the pixel i of the first high frequency channel. According to the present method, W_i is a function of four correlation values C_i, $C_i^{(2)}$, $C_i^{(3)}$ and $C_i^{(4)}$ obtained in four frequency channels for the corresponding (by their location) pixels and the threshold value Δ for the first frequency channel:

$$W_i = W_i\,(C_i, C_i^{(2)}, C_i^{(3)}, C_i^{(4)}, \Delta).$$

It is enough to simplify this function replacing the dependence on three correlation values in other frequency channels $C_i^{(2)}$, $C_i^{(3)}$, $C_i^{(4)}$ by the dependence on their maximum $L = \max\,(C_i^{(2)}, C_i^{(3)}, C_i^{(4)})$:

$$W_i = W_i\,(C_i, \max\,(C_i^{(2)}, C_i^{(3)}, C_i^{(4)}), \Delta) = W_i\,(C_i, L, \Delta)$$

Figure 8 shows the preferred dependence of the weighting coefficient W_i in the first frequency channel on the correlation value C_i in this channel and maximal correlation values in other three channels. This dependence (on 2 variables C_i and L) is illustrated in Figure 8 by the plurality of curves:

curve A for $C_i \geq L$,
curve B for $C_i = 0.7\ L$,
curve C for $C_i = 0.3\ L$,.

curve D for $C_i = 0.1$ L and

curve E for $C_i = 0.01$ L.

The weighting coefficients for pixels of other high frequency channels are defined by the same dependencies.

The weighting coefficient W_i is small if the correlation value C_i is small compared to the threshold value Δ, thus providing noise suppression. Let consider now the case where the correlation value is larger than the threshold value.

Curve A corresponds to the case when the correlation value for the processed pixel in the first frequency channel appears to be higher than correlation values for corresponding pixels in other frequency channels. It shows that the processed pixel belongs to the edge region and the direction of this edge matches the direction of the first channel. Therefore, the weighting coefficient W_i is high, thus providing for edge enhancement.

Concerning the corresponding (by their location) pixels in other high frequency channels, it is to be understood that the lower their respective correlation values are, the lower their weighting coefficients will be (determined according to the same dependencies). These weighting coefficients are always smaller than W_i as the high correlation value of the first channel contributes to maximal correlation value in other channels L and determines using curves B - E. Relatively small weighting coefficients selected for the corresponding pixels in other high frequency channels suppress structures that visually appear as "dust" on sharp edges, thus enhancing visual quality of images.

Curves B, C and D illustrate this suppression. Let C_i being equal to 0.7 L (curve B). Then the highest correlation value between all the corresponding (by their location) pixels appear to be in some other high frequency channel. Consequently, the weighting coefficient C_i in the first frequency channel is lower than the coefficient for the corresponding pixel of some other frequency channel.

Curve E (Figure 8) corresponds to the case of a very small correlation in the first channel compared to other channels. That means that the edges or structures in the first

channel are as weak that can be neglected without any perceptible effect on the image. Therefore, low weighting coefficient is selected for such pixels.

The memory units 26_1 - 26_4 accumulate values of the weighting coefficients generated by the look up tables 25_1 - 25_4. The address generator 27 and adders 28_1 - 28_4 smooth those weighting coefficients in each frequency channel. The smoothing is obtained by summing (in the adder, for example, 28_1) the center value of the coefficient and its neighboring values being sequentially selected from the memory unit (for example, 26_1) by the address generator 27. The smoothed values of weighting coefficients formed on the outputs of adders (for example, 28_1) pass to the outputs of the weighting unit 4.

The operation of the assembling unit is described with a reference to Figure 5. The values of weighting coefficients for four frequency channels pass from the outputs of the unit 4 to the inputs 8_1 - 8_4 of multiplicators 29_1 - 29_4, whereas the pixel values of the corresponding frequency channels pass from the outputs of the splitting unit 2 to the other inputs 10_1 - 10_4 of these multiplicators. The products of the pixel values by the corresponding weighting coefficients generated by multiplicators 29_1 - 29_4 pass to the inputs of the adder 30. Thereto, the corresponding pixel value of the low frequency channel passes to the input 9 of the adder. The adder 30 adds the pixel value of the low frequency channel to all values of the corresponding (by their location in the image) pixels of the high frequency channels, the latest values are multiplied (in multiplicators 29_1 - 29_4) by their respective weighting coefficients. The memory unit 6 accumulates pixels of the output image.

The embodiment described herein illustrates the method as applied to 2D scalar images. It is understood, however, that the claimed method may be applied similarly to 3D images. In this case, in the apparatus used to implement the claimed method, the number of frequency channel increases (preferably to 9 - 13), the 3D Fourier processors are used instead of 2D ones, and the number of pixels in the neighborhood of the processed pixel (used, for example, to compute a correlation value) is 26 instead of 8.

The claimed method may be applied also to processing vector images, particularly the color images. Thereat, the 3 components of a vector presenting a pixel value may correspond,

for example, to the intensity of the 3 basic colors for this pixel. In this case, the scalar operations on pixel values, like Fourier transform and summing, are replaced by the corresponding vector operations as it is known in the art and the correlation is computed as a scalar product of the center pixel value and the weighted vector sum of its neighbors, thereat the vector adder contains as many scalar adders as the number of vector components.

While there was disclosed what is considered to be the preferred embodiment of the invention, it is to be understood that this embodiment is given by example only and not in a limiting sense. Those skilled in the art may make various modifications and additions to the preferred embodiment chosen to illustrate the invention without departing from the spirit and scope of the present contribution to the art. Accordingly, it is to be realized that the patent protection sought and to be afforded hereby shall be deemed to extend to the subject matter claimed and all equivalence thereof fairly within the scope of the invention.

What is claimed is:

1. The method of image processing, comprising the steps of:

providing an original image as a matrix of discreet picture elements (pixels),

splitting said original image into n frequency channels, each of said n channels being presented by an image matrix of the same size as said original image,

detecting edges, and

assembling an output image from said n frequency channels taking said detected edges into account,

wherein said splitting said original image is performed into a low frequency channel and n-1 high frequency channels,

wherein said detecting edges is performed by

calculating in each of said n-1 high frequency channels for each pixel a correlation value between a processed pixel and its neighboring pixels followed by

comparing said correlation value with correlation values for the corresponding (by their location in the image) pixels in other said high frequency channels and with a first threshold value for this channel; and

forming weighting coefficients based on the results of said comparing for each pixel of each of n-1 high frequency channels, and

said assembling said output image is made by summing each pixel from said low frequency channel with all the corresponding (by their location in the image) pixels of said n-1 high frequency channels multiplied by their weighting coefficients.

2. The method according to claim 1, wherein said forming weighting coefficients for each pixel of said each of said n-1 high frequency channels is made by comparing said corresponding correlation value to said first threshold value.

3. The method according to claim 2, wherein a weighting coefficient takes a minimal value for correlation values that are significantly smaller than said first threshold value; said

weighting coefficient smoothly increases from its minimal value to its maximal value for correlation values that are close to said first threshold value; and said weighting coefficient takes its maximal value for correlation values that are significantly larger than said first threshold value.

4. The method according to claim 2, wherein a weighting coefficient takes a minimal value for correlation values that are significantly smaller than said first threshold value; said weighting coefficient smoothly increases from its minimal value to its maximal value while said correlation value increases to a second threshold value, said second threshold value being equal to a product of said first threshold value by a pre-defined coefficient; and said weighting coefficient smoothly decreases from its maximal value to its limit value while said correlation value is larger than said second threshold value.

5. The method according to claim 1, wherein m of said n-1 high frequency channels, where $2 \leq m \leq n-1$, are different from one another in a direction of their principal passing only.

6. The method according to claim 5, wherein said forming weighting coefficients for each pixel of each of said m high frequency channels is made by comparing said corresponding correlation value to said first threshold value and to said correlation values for corresponding (by their location in the image) pixels of other m-1 high frequency channels.

7. The method according to claim 1, wherein each of said picture elements (pixels) is represented by a scalar value characterizing, for example, image intensity at said pixel.

8. The method according to claim 7, wherein said scalar value is calculated for each pixel by multiplication of said pixel value by a weighted sum of its neighboring pixels.

9. The method according to claim 8, wherein m of said n-1 high frequency channels, where $2 \leq m \leq n-1$, are different from one another in a direction of their principal passing only, and anisotropic weights are used for calculating said weighted sum of said neighboring pixels, a direction of said anisotropy corresponding to said direction of principal passing for a corresponding processed frequency channel.

10. The method according to claim 7, wherein said threshold value for each of said n-1 high frequency channels is determined by analyzing distribution of pixel values in an image of a corresponding processed frequency channel.

11. The method according to claim 7, wherein said threshold value for all said frequency channels is determined by analyzing distribution of pixel values of said original image.

12. The method according to claim 1, wherein said picture element (pixel) is represented by a vector.

13. The method according to claim 12, wherein said correlation value for each pixel is calculated as a scalar product of said pixel vector by a weighted sum of vectors representing its neighboring pixels.

14. The method according to claim 13, wherein m of said n-1 high frequency channels, where $2 \leq m \leq n-1$, are different from one another in a direction of their principal passing only and anisotropic weights are used for calculating said weighted sum of said neighboring pixels, a direction of said anisotropy corresponding to said direction of principal passing for a corresponding processed frequency channel.

15. The method according to claim 12, wherein said threshold value for each of said n-1 high frequency channels is determined by analyzing distribution of absolute values of vectors representing pixels of an image of a corresponding processed frequency channel.

16. The method according to claim 12, wherein said threshold values for all high frequency channels is determined by analyzing distribution of absolute values of vectors representing pixel values of said original image.

17. The method according to claim 1, wherein correlation values for several neighboring pixels are smoothed before said forming said weighting coefficients, said smoothing being implemented at least in one of n-1 high frequency channels.

18. The method according to claim 17, further including non-linear transforming said correlation values prior to said smoothing said correlation values, said non-linear transforming remaining unchanged those of said correlation values that are smaller or close to said first threshold value, and decreasing those of said correlation values that are significantly larger than said first threshold value.

19. The method according to claim 1, further comprising smoothing said weighting coefficients over neighboring pixels, said smoothing being implemented at least in one of said n-1 high frequency channels.

20. The method according to claim 1, wherein said original image is a p-dimensional matrix of said picture elements, where p is greater than or equal to 3.

21. The method according to claim 1, wherein different threshold values are used for different parts of said image, said different threshold values being used to form said weighting coefficients at least in one of said n-1 high frequency channels.

22. The method according to claim 21, wherein a picture element of said picture elements is represented by a scalar value and said threshold values for said different parts of said image and different high frequency channels are determined by analyzing distribution of pixel values in a corresponding part of said image of a corresponding frequency channel.

23. The method according to claim 21, wherein a picture element of said picture elements is represented by a vector and said threshold values for said different parts of said image and different frequency channels are determined by analyzing distribution of absolute values of vectors representing pixels in a corresponding part of said image of a corresponding frequency channel.

24. The method according to claim 1, wherein a picture element of said picture elements (pixel) is represented by a complex value.

25. The method according to claim 24, wherein said calculating said correlation value for each pixel is made by multiplication of a value of said pixel by a complex conjugate of a weighted sum of its neighboring pixels.

26. The method according to claim 25, wherein m of said n-1 high frequency channels, where $2 \leq m \leq n-1$, are different from one another in a direction of their principal passing only and said weighted sum of the neighboring pixels is calculated by using anisotropic weights, a

direction of said anisotropy corresponding to said direction of principal passing for a corresponding processed frequency channel.

ABSTRACT OF THE DISCLOSURE

IMAGE PROCESSING METHOD

Image processing method comprises providing an original image as a matrix of discreet picture elements, splitting the original image into n frequency channels, each channel being presented by an image matrix of the same size as the original image, detecting edges, and assembling an output (enhanced) image from the n frequency channels, the assembling taking the detected edges into account. The n frequency channels are represented by a low frequency channel and n-1 high frequency channels while splitting the original image into frequency channels, and the edge detection is performed by calculating a correlation value between processed pixel and its neighboring pixels in each of n-1 selected high channels followed by comparing the correlation value with that for the corresponding pixels in other high frequency channels and with the threshold value for this channel. Based on the results of the comparison, weighting coefficients are formed for each pixel of each of the n-1 high frequency channels, and the assembling of the output image is made by summing each pixel from the low frequency channel with all products of the corresponding (by their location in the image) pixels of n-1 high frequency channels by their weighting coefficients. The method enhances image sharpness and contrast in conjunction with simultaneous noise suppression.